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PHOSPHORUS REMOVAL BY TRICKLING FILTER SLIMES

A. E. Zanoni

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Phosphorus Removal By Trickling Filter Slimes

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16. Abstract

A rotating disc apparatus was constructed so that disc speed could be varied. Organisms that developed on the disc surface, in response to various nutrient solutions, could be harvested and analyzed. Correlations were attempted between mineral composition of the feed solutions and the phosphorus and nitrogen content of the resulting slimes.

An inclined channel apparatus was also constructed and evaluated to differentiate physical or chemical mechanisms from biological mechanisms of phosphorus uptake. The angle of inclination was used to measure the kinetic rates before and after inactivation of the biological slime with ultraviolet light.

With the disc apparatus, limited success of inducing biological uptake of phosphorus, in excess of 1.5 to 2.5 percent of the cell mass, was obtained. Statistical analysis of the data indicated that those values above 2.5 percent usually were encountered when the medium contained calcium salts. Results from the inclined plane growth chamber showed that the limited phosphorus uptake that did occur could be related to metabolic activity rather than physical sorption or chemical precipitation. (EPA)

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PHOSPHORUS REMOVAL BY TRICKLING FILTER SLIMES

by

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Grant #17010 DZG

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ABSTRACT

At the time this investigation was started almost all the reported work in the literature on the biological removal of phosphorus had been with the activated sludge wastewater treatment process. Little information was available on the trickling filter performance in this regard. This is surprising since there are many units of this type in operation in the country today. The published data plus the writer's own experience indicated phosphorus removal for the trickling filter process from negligible amounts to as much as 20 per cent under currently operating schemes.

A review of recent investigations on the behavior of fixed biological slimes plus a degree of similarity between slime biota suggested that the potential for phosphorus removal by trickling filters, and other processes using slimes growing on solid surfaces, is higher than the values which have been reported. The primary objective of this research project was to explore the possibility of greater phosphorus uptakes by biological slimes growing on a solid surface as the result of varying such conditions as slime thickness, feed constituents, growing environment, etc.

Two laboratory units were built in an attempt to study phosphorus uptake by biological slimes. The first consisted of four parallel discs rotating within separate reaction vessels. Slime was grown on the discs under many different operating conditions with little success in obtaining "luxury" uptake of phosphorus. The disc slimes usually contained 1.5 to 2.5 per cent phosphorus on a dry weight basis. In the cases where the values were above this range, it was usually because of the presence of the calcium added to the feed.

The other unit consisted of an inclined surface which contained four one-half inch wide channels of varying lengths for growing slimes. Provisions were included for varying the slope and subjecting the slime surface to ultraviolet irradiation. Basically the results of the test conducted on this apparatus demonstrated that phosphorus uptake on a slime surface is almost entirely due to a biological mechanism with physical adsorption playing a very minor role.

This report was submitted in fulfillment of Project Number 17010 DZG under the sponsorship of the Environmental Protection Agency by the Department of Civil Engineering, Marquette University, Milwaukee, Wisconsin 53233. The Project Engineer was A. E. Zanoni.

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SECTION I

CONCLUSIONS

1. For the analysis of total phosphorus, the ashing method proved to be superior to the persulfate method for sludges and semi-solids like biological slimes. Due to its simplicity and accuracy the persulfate method is still recommended for the routine analysis of water and wastewater samples.

2. A satisfactory method was developed for estimating the per cent carbon in slime samples by using a modified COD procedure.

3. A large number of slime samples from six different trickling filter plants in the Milwaukee area were analyzed with the results that the volatile solids were mostly in the 70 to 80% range, phosphorus in the 2 to 3% range, nitrogen in the 6 to 8% range and carbon in the 40 to 50% range.

4. A number of tests were conducted in which slimes from actual trickling filters were incubated under anaerobic conditions and the phosphorus release properties were examined. Initially a small amount of phosphorus is released to the surrounding liquid but the bulk of it remains tied up in the solid fraction. This indicates that most likely most of the phosphorus in actual slimes is tied up in chemical precipitates.

5. Slimes were grown on the disc apparatus under varying feed and environmental conditions. The amount of total phosphorus in the slime varied from approximately 0.3 to 3.0% for all the test runs conducted. The low values occurred under conditions of phosphorus deficiency in the feed, whereas the high value usually occurred when some calcium hardness was added to the feed.

6. The results of the disc study indicated that there is little likelihood of increasing the amount of biologically stored phosphorus much over 2.0 to 2.5 percent. This means for most municipal wastewaters, a phosphorus removal of less than 20% will usually be achieved under ideal conditions, considering average hardness and the present phosphorus levels in raw wastewater. Chemical addition will be required to increase phosphorus removals above this level.

7. It is difficult to control the biological removal of phosphorus by slimes at any given level, which means the biological phenomenon involving phosphorus uptake is much more random or unpredictable than the better known carbon removal kinetics.

8. Through the use of the channel apparatus a clearer insight as to the mechanism of phosphorus uptake on a slime surface was obtained.

The mechanism was shown to be almost entirely due to biological activity. Physical adsorption which is very important in the soil regime, is of little importance when it comes to slimes growing on solid surfaces. Had physical adsorption proven to be more significant, this would have had interesting implications in the design of treatment units using biological slimes.

SECTION II

RECOMMENDATIONS

At the time that this study was proposed a number of papers had occurred in the literature purporting that luxury biological storage of phosphorus was possible in the activated sludge process under certain plant operational and environmental conditions. Those observations plus the fact that little was known about the trickling filter process in this regard served as the primary impetus for this study.

It has since been fairly well established that the luxury uptake of phosphorus in the activated sludge process was probably due to chemical precipitation with the normal hardness-causing cations under favorable pH conditions. It is the conclusion of this study that the biological removal of phosphorus by slimes growing on solid surfaces is also quite limited, simply because the quantity of biologically fixed phosphorus in slime on a dry weight basis will not exceed 2.5% regardless of environmental and operating conditions. Phosphorus must be incorporated into the sludge if it is to be removed from a wastewater. The only practical way of achieving this in the trickling filter process is by chemical addition. The results of this study strongly suggest that further investigation along the lines of this reported study not be encouraged. The only situation in which biological removal of phosphorus might be worth considering is the case of a wastewater with a high carbon to phosphorus ratio. Even under this ideal case it will probably be found that the control of the operation will be quite difficult.

As far as phosphorus removal from trickling filter plants is concerned, it is recommended that further study be given to optimizing chemical methods, with particular attention being given to type of chemical, point of application, and effect of recirculation schemes. It is also recommended that further attention be given to the fate of phosphorus once it is incorporated in the plant sludge, particularly if anaerobic digesters are involved.

SECTION III

INTRODUCTION

The fact that the rapid euthrophication of many lakes throughout this country is one of the major water resources problems today needs no real convincing. There is almost unanimous agreement among water experts from government, education and industry that this problem is one of the most vexing ones challenging the water resources field presently and most probably for many years in the future. Numerous articles which have appeared in the technical journals and other publications in the last decade or so concur that the rate of natural aging of many inland lakes has been accelerating in recent years, and that this upward trend is the result of the increasing quantities of "nutrients" which are finding their way to these waters (1) (2) (3). These additional loads stem primarily from the varied activities of man residing in the watershed. Most investigators agree that the most important "nutrients" are the various inorganic forms of nitrogen and phosphorus. Of the two elements, the current thinking appears to be that the latter is usually the "limiting" one, meaning, of course, that the extent of eutrophic activity is governed principally by the concentration of the phosphate ion.

One principal source of phosphorus to natural water bodies is the effluent of wastewater treatment plants. A recent study by Ferguson (4), for example, showed that 44 to 56 percent of man-generated sources of phosphorus in U. S. waters originate from domestic sewage. Another report (5) prepared by FWPCA for the Great Lakes Region states that, "about two-thirds of the present annual supply of phosphate going into Lake Michigan (estimated to be about 15 million pounds) comes from municipal and industrial wastewaters".

Information of this nature has been the major impetus in recent years to develop methods for effective phosphorus removal from wastewaters. Early work has been devoted to chemical removal methods which have proved to be effective but comparatively costly. Removal of phosphorus by activated sludge treatment has been shown to be possible at certain plants and under certain operating conditions but there are still some unanswered questions in this area. Very little and inconclusive information is presently available on the potentiality for phosphorus removal by trickling filters.

There has been discussion in some quarters that interest in phosphorus will wane if in fact phosphate detergent builders are replaced with other materials. Assuming as an extreme that all the phosphorus is taken out of the detergent formulations, the concentration of phosphorus in municipal wastewaters from human wastes alone will still be in the range of 3 to 4 mg/l. With an increasing population this amount can continue to have a deleterious effect on receiving waters. This lower value does offer a greater possibility of removing a large percentage of the influent phosphorus through the optimization of current biologi-

cal processes alone, and without chemical additions. This prospect is quite dim with the current phosphorus concentrations in wastewaters.

Assuming solids removal is not a problem, all biological wastewater treatment methods depend upon one essential fact, that is, the optimal growth of microorganisms. It is through this growth that soluble organics (or biochemical oxygen demanding materials) are incorporated into particulate mass or sludge. In addition this growth requires the presence of nutrients, growth factors and trace salts in the wastewater to be treated. Two nutrients of principal concern are nitrogen and phosphorus since limitations in either could impair the growth of the organism involved. Optimum growth necessitates that a balanced quantity of organic matter (carbon) and nutrients be available. A wastewater would be considered nutritionally balanced with a carbon:nitrogen: phosphorus ratio of approximately 50:5:1. This means that the actively growing microorganism in the bio-mass of a biological treatment plant would be extracting these elements in approximately this proportion assuming, of course, proper environmental conditions as well as the proper ratio of bio-mass to available food. If the bio-mass or sludge is effectively removed from the system, the effluent discharged should contain low quantities of carbonaceous matter and nutrients.

Usually, however, the above situation is not the case and because of poor operation or nutritional imbalance, nutrients are present in the final effluent of a biological treatment process. It is not unusual, for example, for the carbon: nitrogen: phosphorus ratio of a domestic wastewater to be in the range of 10:5:1 which means, of course, that it is nutrient rich. In such a case it is very difficult to produce an effluent low in nitrogen and phosphorus through biological synthesis mechanisms alone.

This study is concerned with the removal of phosphorus by trickling filter slimes. The removal of phosphorus by means of bio-slimes of the type present on a trickling filter medium or surface is governed by the same limitations stated above. Considering the nutritional balance concept there is no question that some amount of phosphorus will be incorporated into the bio-mass following contact with the wastewater stream. The question is, however, can this amount be enhanced by employing certain operational schemes? Is there theoretically a range of biological phosphorus uptake possibilities depending upon certain environmental or operational conditions? The above questions do not preclude the certainty that a biological maximum uptake does exist, since it can be stated unequivocally that it does exist. The questions are directed to an elucidation of the possible enhancement of phosphorus storage in the slime, and to a better understanding of the reasons for the variations in reported values of phosphorus removal by trickling filter plants. It is to these ends that this research project is primarily directed.

In a sense, the significance of this research can best be described by considering a hypothetical community with a population of approximat-

ely 1,000. This community finds itself in the same quagmire that many other small communities throughout the U.S. find themselves. Assume that it has an existing trickling filter plant which is common for small communities. The plant is up to capacity and operating as well as can be expected on a BOD and suspended solids basis. It is located in the watershed of an inland lake and regulatory agencies have decided with valid reasons that phosphorus discharges must be abated or significantly reduced. The questions that a community in this situation first ask are what alternatives are available? Is chemical treatment the only answer? Is there any way in which the existing plant can be operated which will enhance the amount of phosphorus removal using existing plant facilities or with minor modification or additions of equipment? If chemical treatment must be used, what is the most effective method of its implementation with an existing trickling filter plant?

SECTION IV

LITERATURE REVIEW

Recent literature reviews by Nesbitt (6), Campbell (7) and Spiegel and Forrest (8) on the topic of phosphorus removal divide the present available schemes under three main headings. They are chemical methods, biological methods and combined biological-chemical methods.

Of these methods, earliest attention has beer given to the chemical methods. These methods involve the use of calcium, aluminum or iron salts to precipitate the phosphate ion out of solution. The work of Malhotra et al. (9), Duff et al. (10), Wukasch(11), Leary and Ernest(12) and Schmid and McKinney (13) among numerous other works, have all clearly demonstrated the effectiveness of phosphorus removal from wastewater using this scheme. Recent works by Ferguson et al. (14), (15), have demonstrated, however, that this chemical precipitation mechanism is not a simple one but rather quite complex because of the significant effect of such variables as pH, time, carbonate and magnesium concentration. In addition, these studies have cast new light on the biological vs. chemical phosphorus removal mechanism arguments which have appeared in the literature in recent years.

Following the interesting investigations of Levin and Shapiro (16), Vacker et al. (17) and Scalf et al. (18), there has been much interest in the biological methods of phosphorus removal. Most of the recently reported investigations have, in addition to the three noted above, been confined to the activated sludge wastewater treatment process. In all of these investigations it was demonstrated that under controlled operational conditions excess or "luxury" uptake of phosphorus by the activated sludge mass can be accomplished. The rapid removal of a fixed percentage of this phosphorus enriched sludge in the final clarifiers results in the phosphorus removal from the wastewater. Early studies have concluded that the phosphorus removal activity is the result primarily of a biochemical mechanism, whereas more recent studies (19),(20), (21), (22), (23) suggest that other factors in addition to biochemical ones may also be operative.

The combined biological-chemical methods are merely the combination of the methods already discussed. The metal salts are generally added to the mixed liquor of the activated sludge aeration basin causing both a chemical and biological fixation of the soluble phosphate ion. Methods of this type have been described by Nesbitt (6), Hubbell (19), Barth et al. (24) and Brenner (25).

Somewhat related to the above topics is the question of phosphorus release during the digestion of waste biological sludges and the impact of supernatant recycling on overall phosphorus removal. Interesting studies addressed to the question have been reported by Ries et al.(26), Dunseth et al. (27), and Malhotra et al. (28).

A review of the literature shows rather surprisingly a serious dearth of information on the effectiveness of the trickling filter process for phosphorus removal. Though one of the most often used biological treatment processes, it is almost totally ignored in most reports or studies dealing with phosphorus removal. The writer became interested in the performance of trickling filters in this regard after conducting a few phosphorus removal surveys at several small trickling filter plants in the Milwaukee metropolitan area. The results all clearly showed that poor to negligible removals were being obtained.

The data that are available in the literature seem to concur with the above findings. Vacker et al. (17) presented some data from four large trickling filter plants showing phosphate reductions varying from 2 to 22 percent. Hubbell (19) stated flatly that, "Experience has indicated that the trickling process will not remove soluble phosphate". Brenner (25) and Barth et al. (29), recently presented some preliminary results on a full plant scale study at Fairborn, Ohio. After a four-week study where they dosed one-third of the 3 mgd plant with sodium aluminate just prior to distribution on the rock media, they obtained an overall phosphorus removal of 65 percent. The phosphorus removal across a control filter at the same plant was only 15 percent. A rather lengthy report was recently written by Benson (30) in which he reported on the performance of four trickling filter plants in Wisconsin. In the case of phosphorus, both the literature review and the actual operating data strongly concur with what already has been stated above, that is, phosphorus removals by trickling filter plants is generally below 20 percent. Finally, a recent study by Jebens and Boyle (31), using a pilot unit, showed that "luxury" uptake of phosphorus was really the result of chemical precipitation of phosphorus with cations present in the hard water wastewater.

Upon examination of some of the recent interesting works by Hartmann (32), Kornegay and Andrews (33) and Maier et al. (34) on the kinetics of substrate removal by fixed slimes, it is difficult to accept without question that the trickling filter process has no potential for exhanced phosphorus removal. Though these studies were concerned with uptake of soluble carbon compounds, nutritive balance requirements and luxury uptake possibilities suggest higher phosphorus uptake rates than present evidence indicates is possible. Also, the similarity of this biota to that found in the activated sludge process - - at least from the standpoint of the basic types of micro-organisms rather than the relative numbers of each - - further suggests the possibility of higher uptake rates.

SECTION V

BASIC OBJECTIVES OF THE STUDY

The primary objective of this investigation was to study in detail the behavior and characteristics of fixed biological slimes from the standpoint of phosphorus uptake. The study was confined almost exclusively to the laboratory phase of this problem, and it was not the original intention to include any full scale trickling filter plant operational studies relative to the question of phosphorus removal. It was hoped, however, that the results of this work might suggest certain operational or design changes of the trickling filter process in order to enhance phosphorus removal. The fact that soluble phosphorus might be recycled to the head end of the treatment plant as a result of its release into digester supernatant liquor was not of concern to this study. Of course, this would be of concern in an actual plant. The principal objective of this study was to examine the factors which control or have some impact on the quantity of phosphorus which is "biochemically" incorporated into fixed media slimes. Once the phosphorus is incorporated into the slime it is in effect removed from the soluble phase. To keep the phosphorus in the slime and to remove it from the plant becomes a sludge disposal problem. Admittedly this latter question is not a simple one and, in fact, could be one of the principal stumbling blocks in effective biological phosphorus removal. At any rate, this aspect of phosphorus removal was not considered to be within the scope of this investigation. To put it very succinctly, the primary intention of this study was to establish if certain environmental conditions or cell growth factors cause an increase in the amount of phosphorus stored in the biological slime. Could this increase then be repeated using the same set of conditions? Is the initial phosphorus uptake mechanics more the result of biochemical or physical adsorption activities? Will the presence of metallic cations to the level found in moderately hard to hard ground waters enhance the amount of "biological" uptake? Will a greater percentage of algal growth in the biological slime result in more phosphorus storage in the slime? What would be the impact of such factors as dissolved oxygen, slime thickness, nutrient balance, type of carbon source, among others, on the amount of stored phosphorus? All of these questions would appear to be of theoretical interest only, but upon further reflection, they all suggest certain operational or design changes which could be easily incorporated into a trickling filter process.

In order to achieve the above stated objectives, an effective means of growing fixed biological slimes had to be developed. Upon reflection, it was decided to use a rotating disc apparatus for this purpose. In contrast to a full scale trickling filter, in the disc apparatus the media moves past the substrate. This difference was not felt to be important since the main objective of the apparatus is to grow copious amounts of slime as quickly and as simply as possible. In order to evaluate a number of different conditions, the unit was constructed so that four completely isolated parallel units could be operated at the

same time.

In addition to the disc apparatus, another experimental unit was constructed to study the mechanism of phosphorus uptake on biological slime. This apparatus is referred to as the "channel" unit. Four parallel channels of different lengths for growing slimes were constructed on a movable platform. Provisions were also included to inactivate the biological slimes growing in the channels. Both of these units will be described in greater detail further on in the report.

SECTION VI

ANALYTICAL PROCEDURES EMPLOYED

Except for the analyses and modifications to be described below, the latest edition of Standard Methods (35) was employed as the principal guide in conducting all the analyses used in this investigation. In all cases, controls and blanks were included with all sets of samples which had to be analyzed. Standard curves were checked repeatedly. On several random occasions during the course of the study, new control samples were set up and analyzed. Also a number of different analysts cross-checked procedures.

Total Phosphorus Analysis

Obviously one of the most important analyses of this study was the one for total phosphorus. The term "total phosphorus" can be somewhat misleading and frequently results are misinterpreted because of this problem. In this study total phosphorus analysis as applied to biological slime samples, is the sum total of all phosphorus contained in a weighted quantity of the material. For most of the slime grown on the laboratory apparatus, this phosphorus is primarily the organically bound phosphorus. However, it should be understood that this analysis includes also any phosphorus which might be in the inorganic particulate form. Furthermore, because the slime units were fed with a substrate containing soluble orthophosphate (and in a few cases soluble complex phosphate) it is conceivable that this analysis includes some of these forms also, assuming some of the liquid film adheres to the slime surface. Prior to analysis, however, slime surfaces were routinely washed with distilled water to remove as much of the soluble ortho-phosphates as possible.

At the time that this investigation was initiated, a number of methods were being used for total phosphorus analysis, but none of these were considered satisfactory in releasing completely the organically bound phosphorus. Recently, some methods have been developed using strong oxidants to liberate the organically bound phosphorus. One such method, the "persulfate method," has shown promise due to its simplicity and superiority over other oxidants. However, there was still much variation in the literature regarding the procedure which should be employed. The "ashing method" has been considered a complete oxidation method but it is a very time consuming method. A comparison study of these two methods was conducted to evaluate them in depth for the use in water and wastewater analyses.

For method development, an organic compound of phosphorus (β-glycerophosphoric acid--disodium salt) was chosen to prepare a standard solution such that 1 ml = 0.001 mg P.

In the persulfate method, a number of variables were optimized such as (a) amount of $K_2S_2O_8$, (b) amount of 30% H_2SO_4, (c) boiling time, and

(d) neutralization technique prior to blue color development for colorimetric test.

In the ashing method, the variables examined were (a) amount of $MgCl_2 \cdot 6H_2O$ (13.67% solution), (b) ashing temperature, (c) ashing time, (d) amount of 30% H_2SO_4, and (e) time of heating for hydrolysis.

After developing these two methods for total phosphorus analysis, a method evaluation was conducted by analyzing the various water and wastewater samples listed below which range from liquid to solid samples: Milwaukee river water, Menomonee river water, Milwaukee raw sewage, Milwaukee secondary effluent, biological slime, primary sludge, secondary sludge from the Waukesha trickling filter plant, mixed liquor suspended solids, return activated sludge, and vacuum filter cake. While the complete details of this study are presented elsewhere (36), the general findings are presented below:

(a) The persulfate method is capable of analyzing up to 10 mg of total P in the sample without dilution. In other words, concentrated samples can be treated first and the dilution can be made afterwards. Similar findings were obtained for the ashing method up to 20 mg P.

(b) The persulfate method gave very satisfactory recovery over a wide range of samples, within ±5%; except for the samples of mixed liquor suspended solids, return sludge, and filter cake. The poor recovery with the latter samples is probably due to the interference of iron present in high concentrations. The ashing method appeared to overcome this shortcoming.

(c) The ashing method proved to be superior for sludges and semi-solid samples and worked as well as the persulfate method for liquid samples.

(d) Due to simplicity, ease, and quickness of the persulfate method, this method should find wide application for the routine analysis of water and wastewater samples.

Following the above comparative studies, plus additional ancillary studies concerning the neutralization step and hydrolysis time which were reported in an earlier progress report (37), it was decided that the "ashing method" for total phosphorus analysis would be the most accurate for this particular investigation. The final procedure employed is as follows:

The slime was dried in a weighed crucible at 103°C for 8 hours. After drying, it was returned to a dessicator and cooled for 8 hours and weighed again. Following weighing, 2 ml of 13.67% $MgCl_2$ were pipetted into the crucible containing the dried sample. The mixture was evaporated to dryness at 103°C, then ashed at 600°C for 2 hours. After cooling,

3 ml 30% H_2SO_4 were pipetted into the crucible and the sample was hydrolyzed on a steam table at 95°C for not less than 45 min., but not more than 60 min. Immediately following hydrolysis, the sample was quantitatively transferred to a 200 ml volumetric flask and diluted to mark with deionized water. The contents of the flask were thoroughly shaken, and a 2 ml aliquot (or volume to give a %T not less than 20 nor greater than 80) was transferred to a nessler tube. The sample was diluted with deionized water, 1 drop of phenophthalein indicator was added, and 5N NaOH was added, drop by drop, shaking after each addition, until the first pink color remained after shaking. The sample was then diluted to mark (100 ml) with deionized water. Four ml ammonium molybdate reagent (See Ref. 35) and 0.5 ml (10 drops) stannous chloride reagent were added, with thorough shaking after each addition. After 10 minutes, but before 12 minutes, using the same specific time interval for all determinations, the color was photometrically measured on a Beckman D.B. Spectrophotometer using a 1 cm light-path at a wavelength of 690 mu and compared to a standard calibration curve. A blank was also set up using deionized water plus all the same reagents used in the sample. The phosphorus content was recorded at a %P on a total dry weight basis.

Standard calibration curves have been made for orthophosphate using KH_2PO_4 as a standard, complex phosphorus using $Na_5P_3O_{10}$ as a standard, and organic phosphorus using β-glycerophosphoric acid as a standard.

Kjeldahl Nitrogen Analysis

The Kjeldahl nitrogen test following the procedure in Standard Methods (35) was first run on a standard glutamic acid solution (.2gN/L) to determine recovery and reproducibility. Due to the nature of the samples to be used in this study (solids rather than liquids), a modification had to be made as to the form of the sample used. In this study, the sample was dried at 103°C for 8 hours, cooled in a dessicator for 8 hours, and weighed. It was then quantitatively transferred to a Kjeldahl flask with 300 ml of deionized water. Since it is important that all the dried sample be transferred, it was necessary to carefully scrape the sample from the crucible with a glass stirring rod. From this point on the analysis followed the digestion and distillation procedure as described in Standard Methods (35) and thus both the nitrogen in the ammonia and organic forms were included. The results were expressed as %N on a dry weight basis as follows:

$$\%N \text{ in slime} = \frac{(\text{ml titrant})\ (0.028)}{\text{dry weight}}$$

assuming, of course, that the normality of the titrant was equal to 0.02 and the dry weight was expressed in grams.

Chemical Oxygen Demand

The chemical oxygen demand analysis according to Standard Methods(35) was first run on a standard glucose solution (.4 mgC/ml) to determine

recovery and reproducibility. Again, due to the nature of the samples, a modification had to be made in the procedure. Due to the large amount of oxidizable material present in the samples, it was not possible to use all of the dry weight. It was decided to wash and scrape the dried and weighed sample into a Waring Blender with deionized water and to thoroughly blend for 10 minutes, washing down the sides of the container several times with deionized water. The liquid was then quantitatively transferred to a 500 ml volumetric flask and diluted to mark with deionized water. After thorough shaking, a suitable aliquot (usually 10 ml for actual trickling filter slimes and 20 ml for disc slimes) was taken and transferred to a COD flask. If less than 20 ml of sample was used, the volume was brought to 20 ml with deionized water. From this point on, the analysis followed the procedure outlined in Standard Methods (35).

Initially, the results were recorded only as $\frac{\text{mg COD}}{\text{mg dry weight}}$, but after a short time, it was decided to express them on the basis of %C on a dry weight basis by assuming that the reaction taking place in the exertion of the oxygen demand is mainly due to the oxidation of carbonaceous matter to carbon dioxide. Considering the ratio of the molecular weights of carbon to oxygen in the formation of carbon dioxide, the %C was estimated from the COD data as follows:

$$\%C = \frac{\text{mg COD}}{\text{mg dry weight}} \times \frac{3}{8} \times 100$$

The validity of the above assumption was checked by comparing the %C as determined by the COD procedure against %C as determined by a total carbon analysis conducted in another laboratory. This comparison was made on three separate occasions using both slimes from the laboratory disc apparatus and from a full scale trickling filter. In all cases the slime were dried and divided into two portions, one for each of the two %C analyses. The results are presented below:

	% Carbon
Sample #1 - Disc Slime	
COD procedure, Duplicate Analysis	45.1
	47.8
Total carbon analyzer, Private Lab.	47.9
Sample #2 - Waukesha Trickling Filter	
COD procedure	48.8
Total carbon analyzer, Private Lab.	41.3
Sample #3 - Disc Slime	
COD procedure (Triplicate Analyses)	42.6
	42.0
	41.3

Sample #3 - Disc Slime (cont.	% Carbon
Total carbon analyzer, Private Lab.	43.7

As noted, except for the case of the actual trickling filter slime, the two procedures compared very well. The disparity in the actual slime results may have been due to interfering materials present in the slime. At any rate, the results were felt to be close enough to continue expressing the COD analysis results in terms of %C in the slime on a total dry weight basis.

Metallic Ions

Of early interest in the study was the development of a reliable procedure for the analysis of calcium, magnesium, iron and total hardness in the slime. Because of numerous interfering substances in the slime, particularly actual trickling filter slime, these procedures offered many more problems than had been anticipated.

First much attention was given to evaluating different digestion procedures; namely, using a mixture of nitric and perchloric acids, and using the dry ashing method suggested by Menar and Jenkins (38). In the case of the calcium and total hardness analysis, the samples were titrated with EDTA following the digestion step. Poor endpoints in the titration step stimulated a search for an improved indicator or for inhibitors of interferring substances. The details of these ancillary studies were presented in an earlier progress report (37). With the help of a paper which appeared in Analytical Chemistry (39), the following titration procedures were finally established

(1) Total Hardness

a. Pipette an amount of sample into a porcelain dish and dilute with deionized water to a volume of 50 ml.

b. Add 5-6 ml of buffer and stir; then add 0.25 gm of NaCN and stir;

(the added buffer is needed to offset the effects of the hydrolysis of CN^- in water. The ph must be adjusted to about 10 to effectively perform the titration)

c. Add 4 drops of Erichrome Black T indicator solution to the dish.

d. Add 0.005M EDTA titrant slowly, with continuous stirring, until the last reddish tinge disappears. The endpoint is taken as that point at which the solution turns to a definite blue color.

e. Calculate total hardness as mg/liter of $CaCO_3$ as follows:

$$\text{hardness} = \frac{(A-B)\ C \times 1000}{\text{ml of sample used}}$$

where A = ml of EDTA added for sample

B = ml of EDTA added for blank

C = mg of $CaCO_3$ equivalent to 1.00 ml EDTA

(2) Calcium

a. Pipette an amount of sample into a porcelain dish and dilute to a volume of 50 ml with deionized water.

b. If the sample is very acidic, it should be neutralized with KOH.

c. Add 5 ml of diethylamine and 4 drops of Calcon indicator solution.

d. Add 0.005M EDTA titrant slowly with continuous stirring until the last reddish tinge disappears. The endpoint is taken as that point at which the solution turns to a definite blue color.

e. Calculate the calcium hardness as mg/l $CaCO_3$

$$\text{mg/l } CaCO_3 = \frac{(A-B\ C \times 1000}{\text{ml sample}}$$

A = ml of EDTA added to titrate sample

B = ml of EDTA added to titrate blank

C = mg of $CaCO_3$ equivalent to 1.00 ml EDTA

Because it was felt that the titration procedures would become very onerous once these analyses became a routine part of the investigation, it was decided to look into other methods. Flame photometry was tried for the calcium analysis for a short time but was finally discontinued because of the erratic nature of the results obtained. It was at this time that it was decided to invest in an atomic absorption unit. After conducting a number of ancillary studies, the following procedure was felt to provide an excellent method for the analysis of calcium and magnesium in the slime.

a. Dry the slime thoroughly in a 103° oven in a tared crucible.

b. Cool in a dessicator and obtain the dry weight.

c. Ash at 800°C in a muffle furnace for one hour.

d. Add 5 ml of 2N HCl and digest on a steam table for one hour.

e. Transfer quantitatively to 100 ml volumetric flask and add 10 ml of Lanthanum Oxide solution (1% La, 5% HCl) and 1 ml of potassium chloride solution (100 mg K per ml).

f. Dilute to 100 ml mark with deionized water.

g. Analyze sample on the atomic absorption unit according to instruction manual and obtain magnitude from an appropriate standard curve.

h. Express Ca or Mg in terms of % of dry weight of slime.

The original method used to analyze for iron in the digested slime sample was basically the phenanthroline method of Standard Methods (35). Interferences caused rather erratic results and extracting the iron with iso-propyl ether proved to be burdensome and the results still questionable. The acquisition of the atomic absorption unit proved to be the final solution of this problem.

SECTION VII

ANALYSIS OF ACTUAL TRICKLING FILTER SLIMES

In order to obtain some background data on biological slimes, it was decided to run phosphorus, nitrogen and COD analyses on actual trickling filter plant slimes. The slime was scraped from the surface rock media of six municipal plants in the Milwaukee area. All of the plants are within 25 miles of the City of Milwaukee. Four of the plants treat flows of less than one MGD. These plants are located in Cedarburg, Germantown, Hales Corners and Saukville. The Menomonee Falls plant handles a flow of approximately one MGD, whereas the Waukesha plant handles an average flow of 10 MGD.

After the slime sample was brought to the laboratory, the slime sample was stirred thoroughly before taking aliquots for analysis. Usually the slime had a very dark green color, generally it had an earthy odor, and occasionally it was teeming with small (1/4 inch) pink sludge worms. The slime was analyzed in triplicate for volatile solids, total phosphorus, nitrogen and COD. As discussed previously the mg of COD per mg of dry weight was converted to percent carbon for convenience of expression. The slimes were analyzed at various times to determine if marked variations occur with seasons of the year.

Results on Fresh Trickling Filter Slimes

A summary of the slime analyses is presented in Table I (Appendix). The results are expressed in terms of percent of total dry weight of sample. The values did not vary markedly from plant to plant. The volatile solids were mostly in the 70 to 80 percent range, phosphorus in the 2 to 3 percent range, nitrogen in the 6 to 8 percent range and carbon in the 40 to 50 percent range.

Slime Washing Procedure

Originally the method for washing the slime was to add deionized water to the sample, mix well, and filter with paper on a Buchner funnel using suction. This washing procedure was carried out 3 times. There were several drawbacks to this method and they made it undesirable. Even using coarse filter paper, the pores quickly became clogged. To remove the slime from the filter paper, it was necessary to scrape it off and there was the possibility of also scraping paper into the sample.

The second method tried, and eventually used, was centrifugation. Deionized water was added to the sample and mixed well. The liquor was then put into bottles and centrifuged at 3000 RPM (or approximately 2000 g) for approximately 20 minutes. After this, the supernatant was drawn off and discarded. Fresh deionized water was added to the bottle, and the entire procedure was then repeated. In all, three washings were made on the slime.

Effect of Storage on Phosphorus in the Slime

There has been some evidence published in the technical literature that the storage of bio-mass under low or zero dissolved oxygen conditions results in the release of organically bound phosphorus to the surrounding liquid environment. Most of this reported work has been done with activated sludges. There is also evidence that if the phosphorus is tied up in an inorganic complex, the release is markedly reduced.

It was felt of interest to examine this behavior in actual trickling filter slimes. After storing the slime for a designated period of time in a sealed container, a sample of the sludge was taken for analysis and washed in the manner already described to remove the "solubilized" phosphorus. Low oxygen level in the bulk of the stored sludge was evidenced by the strong septic odors and the darkening of the sludge with time. The volatile solids also decreased with time of storage.

The results of one storage test is presented in Table 2 (Appendix) in which the slime sample was stored in a refrigerator (approximately 4°C). Thus biological activity was reduced and any phosphorus changes in the bio-mass could be attributed to this condition. As noted, however, the stored phosphorus remained constant during the 15 day period. Also there was no difference between the initial untreated slime sample and the initial washed sample, indicating that all the phosphorus is held tenaciously within the slime matrix or held by adsorptive forces to the slime exterior.

The results of room temperature storage on phosphorus release is presented in Table 3 (Appendix) using slimes from three different plants. The results were no different from that of the refrigerated samples. The fact that the phosphorus percentage increased with time of storage is the result of the decrease in volatile solids with time.

The results of 35°C storage on phosphorus percentages in the sludge is presented in Table 4 (Appendix). As noted, the results are not markedly different from those obtained under room temperature conditions. Also there was little difference in the behavior of the slimes from the different plants.

Effect of Anaerobic Storage on Phosphorus in the Slime

The preliminary results on the effect of storage on phosphorus levels in actual trickling filter slimes were of interest and prompted further studies along these lines. It was decided to store the slime under truly anaerobic conditions and at an elevated temperature to speed up the rate of biological activity. Approximately 100 ml of trickling filter slime was placed in a 500 ml Erlenmeyer flask and the remainder of the flask was filled with deionized water. The flask was tightly sealed with a water trap device so that generated gases could be released. A very small void space was provided between the surface of the

supernatant liquid and the bottom of the stopper. Samples of supernatant were taken at various times and analyzed for ortho-phosphate. Deionized water was added to the flask to compensate for the sampling loss. A number of flasks were set up in order to make it possible to periodically analyze the slime itself during the degradation process. When this was done, the flask content was discarded and the phosphorus was then monitored in a new flask.

The results of two of these studies are presented in Tables 5 and 6 (Appendix). As noted in both test runs, the supernatant phosphorus built up to a maximum value of approximately 200 mg/l within four days and remained fairly constant beyond this time up to 26 days of anaerobic storage. There is an apparent inconsistency in the fact that as the supernatant phosphorus level increased, the percentage phosphorus value in the slime remained the same or even increased. As noted previously, the phosphorus percent is calculated on a total dry weight basis and the destruction in volatile solids tends to mask the overall decrease in the phosphorus present in the solid fraction. Considering the data in Table 6 (Appendix) and expressing the percentages of phosphorus in terms of the solids in the slime, shows that this value was approximately 16 percent at the start of incubation and 10 percent 25 days later.

The same approach described above was attempted using a composite slime from the four discs of the laboratory apparatus. The results of this test are presented in Table 7 (Appendix). This test run was beset with more problems than was the case with the actual trickling filter slimes. The laboratory slime was very light and fluffy and tended to rise up to the supernatant liquid during the anaerobic storage period or when disturbed slightly in the process of obtaining the sample. As a consequence the data obtained were somewhat erratic. However, it is evident that there was release of phosphorus to the supernatant. Better than 50 percent of the phosphorus remained in (or with) the slime even after 13 days, which is particularly surprising since this phosphorus was supposedly metabolically incorporated into the slime.

Finally, three additional anaerobic storage studies were conducted, two using actual trickling filter slimes and one using laboratory disc slime, but with the difference that the percent carbon and nitrogen in the slime were also monitored. The results of these studies are presented in Tables 8, 9 and 10 (Appendix).

As noted in all three cases, an immediate supernatant build-up in phosphorus occurs within 5 to 7 days and remains fairly constant from that time on. It could be reasoned that in the case of the actual trickling filter slimes the phosphorus released immediately was from organic sources while that held in the slimes was inorganically bound. Such reasoning does not fully explain the results obtained with the laboratory slime since it is expected that almost all the slime phosphorus is organically bound.

As would be expected, the percent carbon in the incubated slime

samples also decreased with time, which means of course, the organic carbon was converted to methane and carbon dioxide as a result of anaerobic decomposition. The reduction in percent nitrogen indicates that either some of the organic nitrogen in the slime was solubalized or converted to nitrogen gas. These results merely attest to the active anaerobic activity which took place in the vessels during the storage of the slime samples.

Other Studies

The most likely reason for the rather limited release of phosphorus under storage conditions is that the phosphorus in the slime is bound up into some sort of inorganic complex. The metallic ions of calcium, magnesium and iron, among others, would be involved in this complexing activity. It is therefore of interest to have some knowledge of the "total hardness" of the actual trickling filter slimes used in the storage experiments. The procedure for hardness determination has been described earlier in the report. The hardness values found in some of the slimes analyzed are shown in Table II (Appendix). The results are expressed in terms of percent as calcium carbonate. The much lower values for the laboratory slime are expected since the feed solution was made with softened water.

The high hardness values of the slime are not surprising when one analyzes the hardness in the effluents of some of the treatment plants used as sources of the slime. The average hardness and calcium of triplicate analyses of three plant effluents expressed as calcium carbonate are presented below.

Plant	Calcium (mg/l)	Hardness (mg/l)
Hales Corners	210	439
Menomonee Falls	300	593
Waukesha	201	388

SECTION VIII

DESIGN AND CONSTRUCTION OF LABORATORY DISC APPARATUS

Past experience of the writer with slime growth studies, demonstrated that it would be possible to use a rotating disc device to grow the slime required for the phosphorus uptake investigation. Whereas in a conventional trickling filter plant the wastewater is sprayed over a fixed rock media, it was felt that for a laboratory set-up, it would be much more convenient to move the media through the wastewater or test substrate. Also, in contrast to an actual trickling filter plant, the basic purpose of the laboratory disc apparatus is to provide a convenient means of developing copious growths of biological slimes on a solid surface, rather than using this surface activity for the BOD reduction in the influent stream.

A schematic sketch and photographs of the laboratory disc apparatus are presented in Figures 1 and 2 respectively. The apparatus was constructed so that it would be possible to run four test runs in parallel at the same time. The reaction vessels and 10 inch discs were constructed of one-half inch plexiglas. The apparatus was constructed so that it would be possible to run the entire unit under one set of conditions by removing two plugs provided in each of the three interior separation walls. Each reaction vessel was fed by gravity from 19 liter jugs containing the feed solution. The siphon arrangement was set up so that the inlet atmosphere air pressure point was approximately one inch above the point of the siphon discharge line. This made it possible to obtain a fairly uniform rate of discharge since the driving head remained constant. The final adjustment of the discharge rate was made using a pitch-cock on the rubber tubing used for the discharge line. An air gap was provided between the discharge line and the intluent funnel of the reaction vessel to prevent "crawling" contamination of the feed solution with biological slime. The discs were rotated by means of a pulley system connected to a gear reduction unit and an electrical motor. The exact rotational speed was accomplished using a rheostat-type unit controlling current to the motor.

After passing through the reaction vessel and past the rotating disc, the feed solution passed out from the bottom of the unit into a settling cone (plastic Imhoff cones were used for this purpose). The level of the liquid in the reaction vessel and thus the degree of disc submergence was controlled by adjusting the height of the settling cones. The supporting structure for the cones was constructed to easily facilitate this adjustment. Most of the slime which sloughs off the discs was collected in the bottom portion of the cones which were provided with a volumetric scale for estimating sludge quantities. The effluent from the cones was finally directed to large storage jugs. The entire system operated on gravity and, except for the disc rotation, did not depend on mechanical equipment for its operation.

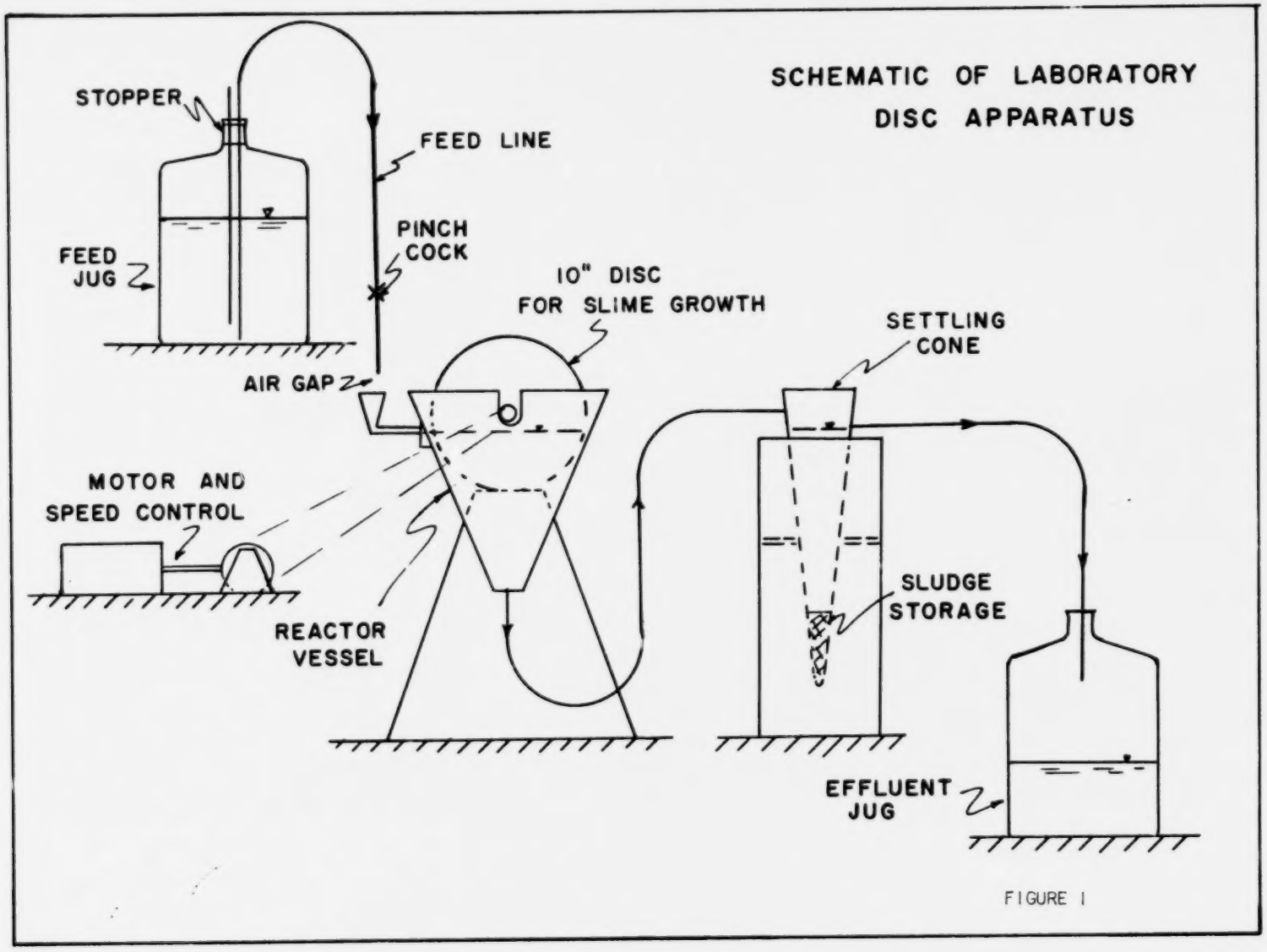

SCHEMATIC OF LABORATORY
DISC APPARATUS
STOPPER
FEED LINE
PINCH
COCK
FEED
JUG
10" DISC
FOR SLIME GROWTH
SETTLING
CONE
AIR GAP
MOTOR AND
SPEED CONTROL
REACTOR
VESSEL
SLUDGE
STORAGE
EFFLUENT
JUG

FIGURE 1

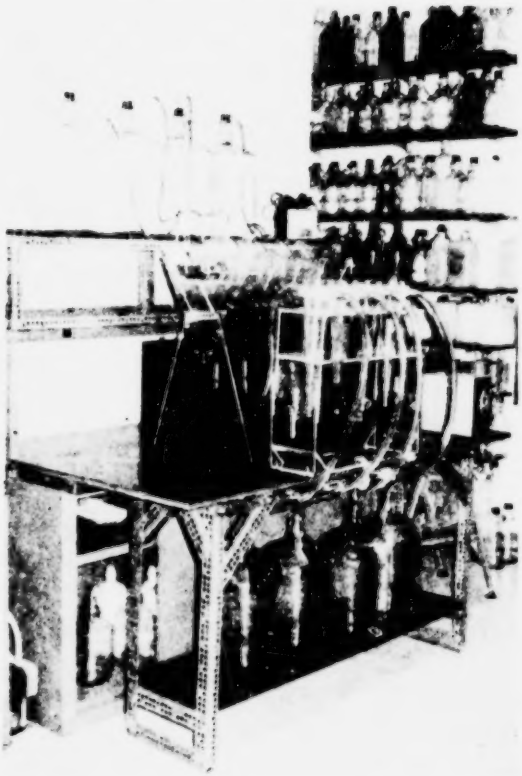


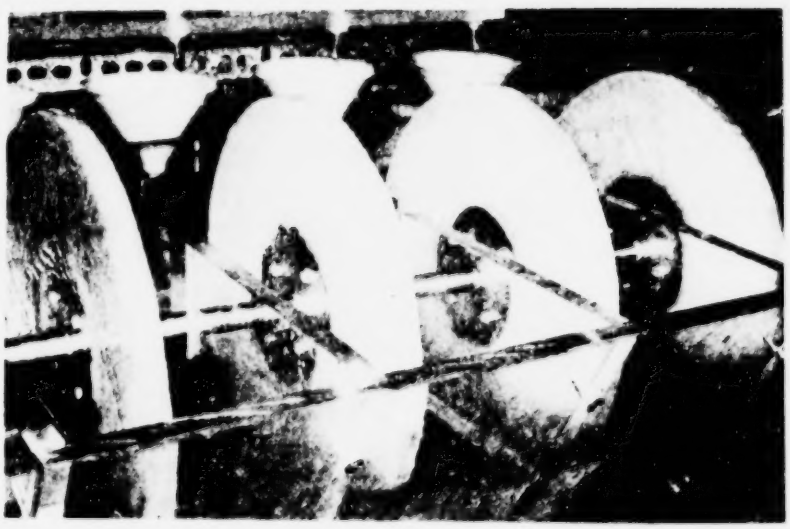
FIGURE 2

PHOTOGRAPHS OF

DISC APPARATUS

(a) overall view of apparatus

(b) close up view of disc with slime



SECTION IX

TESTS CONDUCTED WITH LABORATORY DISC APPARATUS

General Test Procedure

At the start of a test run the disc vessels were seeded with biological slime obtained from a full scale trickling filter plant. The four reaction vessels were then fed a prescribed substrate at the rate of approximately 9 liters per day. The feed carboys were filled with 18 liters of substrate every two days. The feed rates were continually adjusted during this period so that approximately 9 liters of substrate were used up in 24 hours. No attempt was made, nor was it felt necessary, to keep a constant flow rate throughout the entire period.

As the feeding progressed the disc surfaces were frequently examined for evidence of slime build-up. Usually within two to three days a fairly good growth had developed. However, in most cases the units were fed for approximately two weeks before slime samples were obtained for analysis. In a few cases the test runs were shorter and longer than this period, but in all cases the runs were continued to the point where it was felt that the slime growth was completely acclimated to the particular test run conditions.

Just prior to the filling of the feed with fresh substrate, the jugs and siphon assembly were thoroughly washed in a strong bleach solution and carefully rinsed with tap water and distilled water. The air inlet line to the feed jug was plugged with sterile cotton. All the feed jugs were washed with a strong acid solution at the end of each test run.

Each day the walls of the reaction vessels were thoroughly brushed to prevent build-up of any slime. As a result, slime build-up on the walls was minimal. Agitating the vessel contents periodically provided good "seeding" for the disc surfaces. During the course of each run, the pH, temperature and dissolved oxygen were determined in the reaction vessels. A careful log was kept of all activities associated with the test run. Such items as date of jug refill, disc speed check, condition of disc slime, sludge in storage cone, etc. were noted in the log book.

After sufficient time had elapsed for good slime growth development, the disc rotation was stopped and the top half of the slime covered disc was gently washed with deionized water. The slime was then scraped from the surface of the disc with a steel knife blade and placed into a beaker. After completing the top half of the disc, the lower half was exposed and the slime was removed in the same manner. The analyses of the slime were set up immediately after the four scrapings were made. A residual coating, or film, remained on the disc and served as a seed for the subsequent test run. The analyses routinely conducted on the slime were volatile solids, phosphorus, nitrogen and COD. In a few test runs calcium and

magnesium analyses were also conducted. On an average of once per test run, the same analyses were conducted on the feed solution and effluent of the disc units. This was done to provide a random check of the characteristics of the feed solution and to have a record of the "removals" provided by the disc units. As expected, very limited nitrogen and phosphorus removal was obtained, particularly in the runs where excess amounts of these elements were in the substrate. The COD removals were usually around 50 percent. These results were not surprising since this apparatus was designed to grow slime rather than to treat an influent flow.

Attempts were made to measure the slime thickness with a caliper device and a magnifying glass, just prior to the scraping of the slime. Because of irregularity and the "spongy" nature of the slime the measurements obtained were approximate at best. After the thickness was noted, the scraped slime contained on each disc was placed into a calibrated beaker and the volume of "crop" was also noted. Other characteristics of the slime,such as color and texture, were also noted and recorded in the log book.

Specific Test Runs

As pointed out previously, one of the principal objectives of this investigation was to determine under what set of conditions it was possible to enhance the amount of phosphorus storage in biological slime. At the outset, no attention was given to applicability of the condition to a prototype treatment system employing fixed biological slimes for the treatment of wastewaters. The question was simply: Can greater amounts of phosphorus be taken up into biological slimes, and if so, under what environmental and operating conditions? Once this is established, the second question logically follows: Is there any way of incorporating these same conditions in a prototype system to achieve enhanced removals without going to well-known chemical removal methods? The subsequent discussion on the test runs conducted should be viewed with the above objectives in mind.

For the first test runs it was decided to feed the four disc reactors with a specified amount of carbon, nitrogen and phosphorus. The carbon and nitrogen were kept identical but the phosphorus values were varied from a phosphorus deficient feed in the case of the first disc reactor, to a phosphorus rich feed in the case of the last. The nutrient composition on a weight ratio basis selected for the four feeds was as follows:

	C	N	P
Feed I	50	5	0.1
Feed II	50	5	1
Feed III	50	5	5
Feed IV	50	5	10

Feed II would be considered the closest to a nutritionally balanced diet

from the standpoint of the metabolic requirements of most microbial systems, including biological slimes.

For the first series of test runs it was decided to use glucose as the carbon source. The sources of nitrogen and phosphorus were ammonium chloride and sodium phosphate, respectively. The concentration selected for the glucose was 300 mg/l which results in a theoretical COD of 320 mg/l for the feed solutions. With this concentration established, the resulting concentrations of the nitrogen and phosphorus would have to be as follows:

	Concentration (mg/l)		
	Glucose	N	P
Feed I	300	12.0	0.24
Feed II	300	12.0	2.40
Feed III	300	12.0	12.00
Feed IV	300	12.0	24.00

The glucose and the ammonium chloride were added to 80 liters of softened Milwaukee tap water in a large plastic container and the contents were stirred thoroughly. The phosphate salt was added directly to the four jugs. The softened tap water containing the glucose and nitrogen sources was then pumped up to the four feed jugs. A disc speed was selected and maintained for the entire duration of the test run.

Following this initial series of test runs, new operating conditions were employed in subsequent runs. A summary log of all test run conditions, including some remarks on slime characteristics, is present in Table 12 (Appendix). As noted, the operating variables include disc speed, water hardness, type of carbon source, type of nitrogen source, concentration of phosphorus in the feed, absence or addition of a calcium source to the substrate, and whether or not the disc slime was continually subjected to a plant light.

In the nomenclature used to identify each test run, a different roman numeral was used for each carbon source; "A" means the first test run under a set of conditions and "B" means the second test run under the same set of conditions, "H" means hard water was used to make up the feed solution and "S" means soft water was used to make up the feed solution, and the last number represents the disc speed in revolutions per minute.

The term "hard" water is really a relative one since it is Milwaukee tap water which is obtained from Lake Michigan. The hardness of this water is approximately 120 mg/l as $CaCO_3$ which is only moderately hard for a water supply. The soft water was obtained by passing Milwaukee tap water through a zeolite softener. The hardness of this water for all practical purposes is close to zero.

The carbon sources used were glucose, nutrient broth, yeast extract and dry milk solids in various combinations. These same substrates

served as the nitrogen source in addition to ammonium chloride. Sodium phosphate, an ortho-phosphate, was used as the phosphorus source in all cases and concentrations ranging from 0 to 24 mg/l as P were employed. Two sources of calcium were used in those test runs in which this element was added, namely, calcium chloride and lime.

For most of the test runs the disc slime was subjected to the normal diurnal light cycle. The disc apparatus was located in a room with a southern exposure and thus well lighted during the day, in spite of the fact that the shades were down on bright sunny days. On many days the fluorescent ceiling lights were on continually. In spite of this lighting, only a limited amount of green growth developed on the discs. For some of the final test runs it was decided to subject the disc apparatus to 24 hours of special plant lighting* with a wave length for optimal photosynthetic activity, to determine the effect of copious algal growth on phosphorus storage. From the luxurious green growth which developed during these runs, it was apparent good algal growth had occurred.

Results of Tests Conducted With Laboratory Disc Apparatus

The results of all of the test runs described in the previous section are presented in Table 13 (Appendix). The four slime analyses included in this Table are volatile solids, phosphorus, carbon and nitrogen. Calcium and magnesium analyses were also conducted in some of the test runs, and these results are presented in Table 14 (Appendix). Because varying amounts of phosphorus were fed to the four reaction vessels, the results are presented for each of the individual disc slimes. Because of the incompleteness of the data in a number of test runs, not all of the test run data were included in the statistical analyses which will be described subsequently. The test runs included are designated in the Table and as noted, 33 of the 38 runs are included.

Other Operating Observations

A detailed log was kept of the observations made during the operation of the disc apparatus. Early in the investigation it was felt that since a biological process was being operated, these observations might assist in the final interpretations of the data. While such items as slime color, texture and yield may not appear too significant for an individual test run, they might supply some important insight if certain finds were noted in a large number of test runs. For example, runs with high biological phosphorus uptake might be associated with a slime of a particular character. If this proved to be the case, this slime could then be examined in greater detail.

After a number of test runs it became apparent that no discernable trends were developing in this regard. On the contrary, the results were

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*General Electric, Plant Light, F40PL (two lamps)

often conflicting and confusing and thus can be only used in a general qualitative way rather than in a specific quantitative or statistical way.

For most of the test runs the slime had a color in the white-cream-yellow range. Occasionally the slime also had a pink tint but this never persisted. Except for the test runs in which the continuous plant light was employed, very little green growth developed on the disc surface. This was surprising since the apparatus was located in a well lighted room. Copius green colored slime developed during the last test runs when the apparatus was subjected to the plant light. In some of these test runs part of the surface was also covered with a more tan-like growth. In summary, if one examines all of the test run data on slime appearance, no real conclusions can be drawn other than possibly the fact that slime growth is a highly hetereogeneous biological situation.

The same conclusions can be drawn regarding slime texture. At times the slime was very slimey and fragile and had the tendency to break off the disc surface in large chunks. Other times it was much more cohesive. The former condition was more prevalent at slower disc speeds whereas the latter was more apt to be the case at higher speeds. Sometimes this variation occurred in the four discs which were all rotating at the same speed but under varying feed conditions. When the feed solutions contained some hardness, the slime surface on occasions had a more granular texture - - particularly at higher disc speed.

Much attention was given to slime thickness. One of the original premises of this investigation was that slime thickness might have an effect on the amount of phosphorus stored in the biological slime. Speed control of the disc rotation was provided mainly in an attempt to control slime thickness. A caliper device was employed for some of the early test runs to measure slime thickness. This proved to be difficult because of the fragile nature and irregularity of the slime surface. A micrometer was tried for subsequent test runs and this offered somewhat of an improvement. The micrometer was operated under a large magnifying glass mounted on the reaction vessel. The major problem again was the irregularity of the surface. Frequently the slime was quite thin where large chunks of slime had previously fallen off. Thus there were frequent areas of thin and thick slime on the same disc.

In general, the slime thickness was greatest for the slower test runs, namely test runs of 25 RPM disc speed and less. These slimes were usually in the 1/8 to 3/16 inch range of thickness. At higher speeds the slimes were generally thinner; namely in the 1/16 to possibly 1/8 inch range. Any attempt to refine these data beyond the above generalization would be quite futile. This is particularly true when one considers that the slime thickness often varied from one disc to another in the same test run in which all four discs operated at the identical speed.

It is to be expected that as thickness varied so did slime yield. By slime yield is meant the total amount of slime "crop" removed from the

surface of the disc at the end of a test run. Again more crop was usually obtained for the test runs at the slower speed. Though variations occurred above and below these amounts, the amount of yield was generally in the 75 to 100 ml range with a highly variable amount of actual total solids. Obviously slime yield is not the same as the total sludge generated during a test run. No attempt was made to arrive at this latter figure. Slime yield represented the amount of slime carried on disc surface under a given set of operating conditions after achieving a steady-state condition with the substrate in the reaction vessel.

At various times during the course of the investigation the temperature, pH and dissolved oxygen content of the substrate in the reaction vessel were measured. Most of the temperatures were in the 18 to 20°C range and the pH in the 7.0 to 8.0 range. The dissolved oxygen varied depending on the disc speed of the particular test run. At no time did the D.O. ever reach zero. Even for the test runs of 1 RPM disc speed, the D.O. was generally in the 1.0 to 2.0 mg/l range. At disc speeds of 10 to 25 RPM the D.O. increased to the 4.0 to 6.0 mg/l range, and at higher speeds a D.O. of 7.0 to 9.0 mg/l was achieved.

SECTION X

DESIGN AND CONSTRUCTION OF LABORATORY CHANNEL APPARATUS

One question which has been raised regarding the uptake of phosphorus by biological slime is the role that physical adsorption on the slime surface plays in the overall removal process. It is known that this mechanism is very important in natural soils. As far as phosphorus removal is concerned, it makes little difference if the phosphorus is incorporated biologically into the slime or adheres to the slime surface as long as it is removed from the wastewater. If, however, it is determined that surface adsorption is an important part of the overall removal mechanism, the total amount of slime surface area in a fixed medium treatment device would partly control the extent of the total phosphorus which is removed. This is a design feature which could be controlled to some extent by the designer.

A channel apparatus was constructed to study this particular question. A schematic of the apparatus set up is presented in Figure 3. Most of the channel unit was constructed of 1/2" plexiglas. An important design feature was that the slope of the channel plank could be adjusted as desired. The greater the slope, the less will be the time of contact between the slime surface and the phosphorus containing feed solution. Also important was the fact that the four different channel lengths were available on the channel plank. At a given slope, this provided still another variable, that is, total opportunity for slime contact. A photograph of the channel apparatus is presented in Figure 4.

The channels themselves were one-half inch wide and one-quarter inch deep. The channels were constructed so that it was possible to firmly lay down on the bottom a fine fiberglas mesh. The mesh provided an excellent base for the development of the channel slime.

Four positive displacement pumps which operated off the same motor drive were used to bring the feed solution to the head end of the channel. The pumps maintained the desired low rate of flow for extended periods of time with very little variation among the four units. After dropping to the channel surface, the feed solution flowed down the channel to a discharge hole at the end of the reach. Plastic tubing was used to drain the channel effluent into sample jugs.

Brackets were provided at the ends of the channel plank to support an ultraviolet lamp assembly used to inactivate the microorganism on the channel surface. The lamp assembly did not interfere with the influent line of the channel operation.

A special metal tool was designed to scrape the slime growth (or crop) from the channel surface. The scraping edge of the tool was designed such that it lifted the slime off of the bottom mesh.

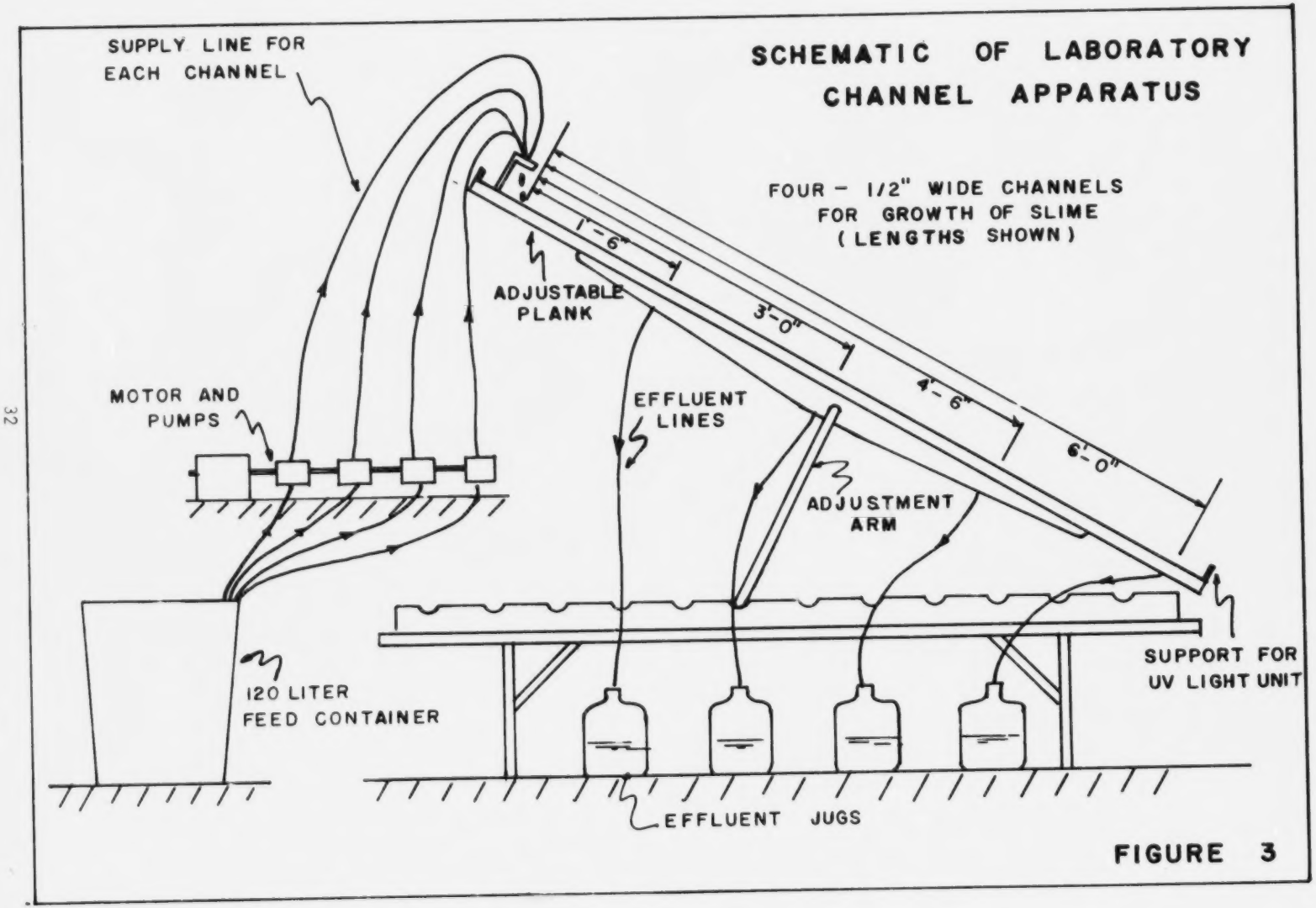
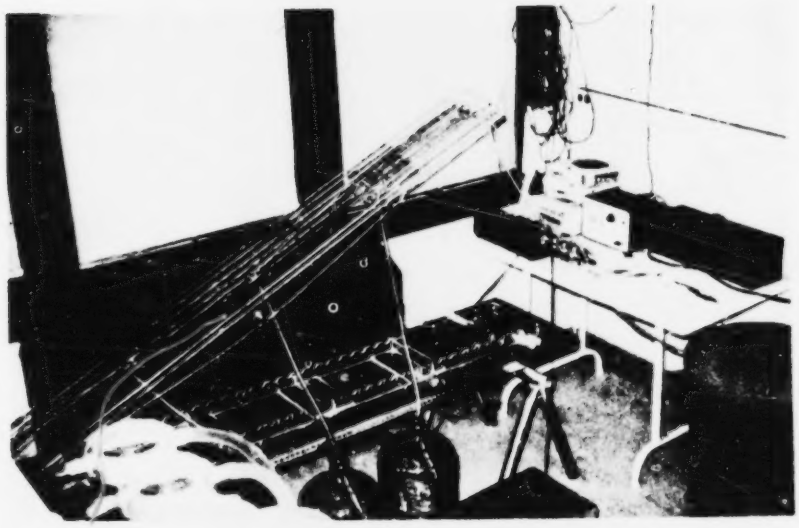

SCHEMATIC OF LABORATORY CHANNEL APPARATUS
SUPPLY LINE FOR EACH CHANNEL
FOUR - 1/2" WIDE CHANNELS FOR GROWTH OF SLIME (LENGTHS SHOWN)
1'-6"
3'-0"
4'-6"
6'-0"
ADJUSTABLE PLANK
MOTOR AND PUMPS
EFFLUENT LINES
ADJUSTMENT ARM
120 LITER FEED CONTAINER
SUPPORT FOR UV LIGHT UNIT
EFFLUENT JUGS

FIGURE 3

FIGURE 4

PHOTOGRAPH OF CHANNEL

APPARATUS



SECTION XI

TESTS CONDUCTED WITH LABORATORY CHANNEL APPARATUS

General Test Procedure

After the channel apparatus was constructed, the first problem was to establish the operating conditions that resulted in a good slime growth in the four channels. The first substrate tried was dry milk solids in varying concentrations but the resulting growth was not too satisfactory. The slime growth was very irregular and "puffy" in texture. Various rates of flow were also tried. When the flow rates were too low (in the range of 1 to 2 ml per minute per channel) the slime growth tended to be irregular and not cover the entire channel surface area. A flow rate of 4.0 ml per minute per channel eliminated this problem. The logistics of supplying enough feed substrate in the continuous operation of a laboratory unit precluded increasing the flow rate too much above the 4.0 ml figure cited above.

Glucose was also tried as the carbon source, supplemented with ammonium and phosphate salts. The characteristics of the slime did not improve much. A combination or nutrient broth and glucose was also tried with limited success. After attempting a number of different combinations, the substrate which appeared to work the best consisted of glucose, milk solids, sodium phosphate and ammonium chloride added to softened Milwaukee tap water. The actual amounts of each of these varied during some of the initial test runs, but for the most of the remaining test runs the channel feed substrate consisted of the following:

80 liters of Milwaukee softened tap water
25 g. dry milk solids (commercial brand)
75 g. glucose
15 ml Na_2HPO_4 solution (containing 20 mg P per ml)
80 ml NH_4Cl solution (containing 48 mg N per ml)

A typical analysis of the above feed solution was as follows:

COD =	1330 mg/l
Kjeldahl N =	65 mg/l
Total-P =	5.5 mg/l

One of the factors which also had a bearing on the characteristics of the final substrate selected was the sensitivity of phosphorus removal within the length of channels available in the apparatus. In some of the original test runs, negligible removals were obtained. There were three reasons for this situation. First, metabolic requirements for phosphorus are quite low relative to carbon and nitrogen and thus little phosphorus will be incorporated into the channel slime even under ideal growing conditions. Second, in some of the initial feed solutions the carbon to phosphorus ratio was too low. Greater phosphorus removal sensitivity can

be obtained by using a carbon rich - phosphorus poor nutritional composition in the feed. Thirdly, the length of the channels themselves afforded a limited amount of "reaction" surface for biological phosphorus removal. The substrate composition described above appeared to minimize to a certain extent the effect of the first two conditions. Not much could be done with the channel length condition since this is governed by the normal physical limitations of a laboratory set-up.

Three different slopes were used during the course of the channel studies. They were as follows:

Slope Designation	Tangent of Slope Angle	Angle
Low	0.0616	3.5°
Mid	0.4412	24.0°
High	0.9537	43.5°

The procedure for starting a test run was essentially the same in all cases. After the feed solution was made up in a 80 liter batch, the solution was seeded with a small amount of slime from a full scale trickling filter plant. Some of the seed material was also rubbed into the fine bottom mesh for the entire length of the channels. After a growth started to develop, the channels were continually fed with fresh feed solution. After a good growth of slime developed, it was scraped down to the level of the fine mesh. Test runs were normally conducted several hours after the slime was scraped. Effluent samples for analysis were collected in erlenmeyer flasks packed in ice. Prior to analysis, the effluent and raw samples were filtered through paper. The procedures employed for the analysis of the liquid and slime samples were the same as those used for disc studies.

Channel Studies Using Ultraviolet Radiation

In order to establish the degree of physical adsorption involved in the uptake of phosphorus by biological slimes, a method of inactivating the surface slime had to be developed. The method used could not alter the surface properties of the slime appreciably since it was necessary that the physical characteristics of the slime surface be the same both before and after the biological inactivation. Only then would it be possible to establish whether the physical adsorption mechanism was important in phosphorus uptake.

Several methods of slime surface inactivation were considered. For example, a solution containing a chemical disinfectant such as chlorine or iodine could be passed down the channel for a short period of time just prior to resuming the test. Another method could be to place the entire channel set-up in the walk-in constant temperature room. The channel apparatus was designed with this possibility in mind. The temperature of the room could be reduced to about 5°C and the slime acclimated to this temperature. At this temperature the biological activity

would be suppressed while the physical characteristics would remain unaltered. Still another possibility was one reported in a paper by Borchardt and Azad (21) in which chemicals like sodium azide, sodium arsenate, iodoacetic acid, and sodium fluoride could be used for the inactivation of phosphorylating enzymes while not harming the cells themselves. Finally, a set-up could be constructed containing a bank of ultraviolet germicidal lamps which could be employed to radiate the channel slime. Keeping in mind the main idea of stopping the biochemical activity of the slime while still retaining the same physical characteristics of the surface, this last method appeared to offer the greatest promise. Thus a number of ancillary studies were conducted to explore its potential.

In the first ancillary test some slime was removed from the disc apparatus and divided into two petri dishes. One was retained as the control, the other was subject to UV light in a commercial unit used for the disinfection of glassware needed for bacteriological tests. After exposing the slime for an increment of time, a piece of sterile gauze was placed gently on the slime and transferred to tryptone glucose extract agar plates. The same procedure was used for the control. Ten exposures with a total cumulative time of 120 minutes were used. After incubation the plates were compared. The UV plates had fewer colonies than the control, but the kill did not appear to be extensive enough. One reason for the poor kill might have been that an irregular (not like a surface growing slime) slime sample was used and the UV radiation could not reach all the surface because of projections.

An undisturbed slime sample, 1-1/2 inch by 1-1/2 inch, was carefully removed from the disc for the second test. The test was conducted as described above, only that 180 minutes of total UV exposure was employed this time. Some kill was noted at 10 minutes. At 20 minutes the kill was good and at 30 minutes it was very good. After 60 minutes there were very few colonies on the plate incubated with the gauze from the UV radiated slime.

Another test was conducted using a slime sample which was felt to be essentially undisturbed. This was accomplished by attaching a small piece of plastic film to the rotating discs. After two weeks the slime growth on the film was continuous with the slime on the remainder of the disc surface. On the day of the test the small film was carefully removed from the disc with the slime completely intact. The results obtained with this slime sample were about the same as those described above.

Except for some minor problems, the results of these ancillary tests were felt to be encouraging and it appeared that this method could be used to inactivate the slime. One problem noted was that in the commercial unit the temperature in the enclosure began to increase with time of exposure. In all of the tests the internal temperature at the point of slime radiation increased from 24°C to 38°C. Such an increase in temperature could be deleterious to the slime surface. The increase in temperature also caused a drying of the slime surface which in turn could change the physical characteristics. When sterile water was placed on the slime surface after a period of UV exposure, it caused an increase

in the number of colonies of the UV plates. The water seemed to resuspend or disturb the surface colonies. This is not surprising since it is known that UV penetration is very minimal, particularly in an aqueous environment. It was felt that the first problem could be minimized by designing the UV light assembly so that the heat dissipated rapidly. The second problem could be minimized by continuing the UV radiation of the slime for long periods while the feed solution was actually flowing down the channels.

The UV light assembly was constructed to completely cover the channel planks which contained the four channels. The depth of the unit was eight inches with the result that the lamps were approximately three inches from the slime surface. Four 36 inch long, commercial germicidal lamps* were mounted in the unit such that all the channel surface was well covered. The top of the unit was constructed of thin gauge sheet metal for good heat dissipation. The sides of the units were constructed of standard window panes. Large openings were provided at the two ends of the unit (influent end and discharge ends of the channels) in order to insure good air circulation. The unit was constructed so that it was well secured to the channel plank and in no way interfered with the slope adjustments or the channel flow arrangement.

Specific Test Runs

As stated previously, a large number of preliminary test runs were conducted in order to establish the most suitable substrate composition for development of the best channel slime. During the test runs, analyses were conducted on the channel feed and effluent. The analyses conducted were total phosphorus, COD and total Kjeldahl nitrogen. During these test runs, analyses were also conducted on the channel slime. These consisted of percent total phosphorus in all cases, plus percent nitrogen, volatile solids and carbon in that order depending upon the amount of channel slime available.

Following the establishment of a suitable substrate, a series of test runs were conducted primarily to determine if the amount of phosphorus uptake varied with the length of channel slime. These tests were conducted at three different slopes to appraise the importance of time of contact on the amount of phosphorus uptake.

As noted previously, one of the main reasons for the channel study was to determine if physical adsorption is part of the mechanism of phosphorus uptake on biological slimes. At this point the UV light assembly was incorporated into the test runs. Two test runs were first conducted as follows. The channel unit was fed with the substrate until a good slime growth developed. Following this development, influent and effluent analyses were conducted as before. The channel unit was then subjected to UV radiation as the channels were fed in the normal manner. Influent-effluent analyses were conducted following varying increments of UV exposure. The longest time of exposure employed was 72 hours.

*General Electric, Germicidal, G30T8

Following these tests a number of "starve-kill" test runs were conducted. The basic idea in these runs was to first grow an active slime and then run a conventional influent-effluent test as described above. The slime was then "fed" with de-chlorinated tap water for 24 hours which kept the slime viable but also in a somewhat starved condition. The channel unit was then fed with the normal substrate while a second test was being conducted. The water feed was resumed for 24 hours, the UV radiation was turned on for two hours with the water feed continuing. At the end of the radiation period, the normal feed was again turned on and influent-effluent analyses were conducted. This procedure was employed at the three different slopes.

Results of Tests Conducted With Laboratory Channel Apparatus

The analysis of channel slimes during preliminary runs using a number of different substrated is presented in Table 15 (Appendix).

The results of feed and effluent analyses for eight test runs is presented in Table 16 (Appendix). It wasn't until test run VI that the test substrate was finally established for the remainder of the channel testing program. Slime analyses conducted during this phase of the testing program are presented in Table 17 (Appendix).

Feed and effluent analyses while the UV assembly was in use are presented in Table 18 (Appendix) and the results of the "starve-kill" runs are presented in Table 19 (Appendix).

SECTION XII

DISCUSSION OF RESULTS

The primary objective of this study was to determine if the amount of phosphorus uptake by biological slimes on fixed surfaces can be enhanced. To accomplish the objective it was necessary to examine how various operational variables, such as, carbon source, concentration of influent phosphorus, dissolved oxygen level, slime thickness, water hardness, and degree of algal growth, influenced the amount of phosphorus stored in the slime. It was also important to understand the mechanism of phosphorus uptake on biological slimes, particularly the importance of physical adsorption on the slime surface.

It was never the intention of this research project to develop a "new process" for fixing phosphorus on biological slimes; but rather, it was to develop a better understanding of this uptake activity, and on the basis of this understanding, establish if it would be possible to suggest ways to enhance the amount of phosphorus removed in the conventional trickling filter process. An enhancement of 15 to 25 percent, if accomplished through relatively simple operational or design changes, would be quite significant. This would be particularly true in the event that the phosphorus additives are eventually eliminated from detergent products. This would lower the amount of total phosphorus in raw waste-water from approximately 10 mg/l to 3-4 mg/l. Well controlled biological treatment might adequately take care of these lower concentrations eliminating the need for more costly chemical treatment. Even at these lower concentrations it would be erroneous to assume that biological treatment will ever provide "total" phosphorus removal.

The research program was mainly centered around two laboratory apparatus which already have been described in detail, namely, the disc apparatus and the channel apparatus. The discussion of the results for convenience will also be divided under the same two headings.

The Disc Apparatus

In spite of the large number of test runs and the various operational conditions used, the percentage phosphorus on a dry weight basis stored in the disc slime ranged from 0.11 to 4.34 percent, as noted in Table 13. Discounting the ten lowest values and the ten highest values, the range decreases markedly to 0.30 to 2.88%, which is a way of demonstrating the central tendency of the data. The range is quite narrow considering that well over 400 different disc slime samples are included. By different samples is meant each is from a new growth on a given disc. It is true that many of the test runs were repeated with identical operating conditions, but each test run resulted in a completely new growth. As noted previously, all slime was scraped from the disc prior to the start of a new run. In spite of the same operating conditions for two different test runs, frequently the slime had a different appearance and consistency. It would be reasonable to suspect that such differences would be the result of the growth of varying biota which in turn might result in a change in the amount of phosphorus stored.

Thus for the purpose of discussion, each slime sample can be considered as being derived from a unique situation.

A cursory observation of Table 13 will show that a vast majority of the percent phosphorus values in the slime vary from 1.5 to 2.5 percent. Values considerably below 1.5 percent occurred primarily in those test runs where the concentration of the phosphorus in the feed was quite low - - in fact a level which would be considered biologically deficient. In these test runs the ratio of carbon to phosphorus was approximately 500 to 1. Under these feed conditions there appears to be enough phosphorus to cause growth but certainly not enough to satisfy the full demand of the growing slime.

On the other hand, values above 2.5 per cent usually occurred in those test runs where some calcium hardness was added to the feed. In general, the greater the amount of hardness in the feed, the higher is the resulting phosphorus stored in the slime. Obviously these higher phosphorus values are not the result of biological activity but the result of calcium phosphate precipitates being incorporated into the slime matrix. This fact is substantiated by the values for percent calcium in the slime, which were also greater for the slime samples in which the phosphorus amounts were greater.

It is much more difficult to explain the reasoning for the variation in stored phosphorus for the range between 1.5 to 2.5 percent. An examination of Table 13 will not show any clear trends or patterns. If anything, the results appear haphazard and random. When one thinks he has an explanation for the results of a particular run, the hypothesis is quickly refuted in a subsequent run.

In an attempt to derive some meaning from the spate of data available from the disc apparatus, it was decided to subject the data to a multiple correlation analysis using a digital computer. The method employed is based on the assumption of linearity in the relationships among the variables. The purpose of this statistical analysis is to establish which of the independent variables have the greatest significance in controlling the eventual percent phosphorus stored in the slime. The data employed as independent variables include disc speed, concentration of COD, N, P and Ca in the feed, and percent volatile solids, C and N in the disc slime, whereas, the percent P in the slime was naturally the dependent variable. The results of the multiple regression analysis for the data from each of the four discs is presented in Tables 20, 21, 22 and 23. A summary of two common statistics used to characterize multiple regressions is presented in Table 24.

The results of this statistical analysis are by no means conclusive. However, keeping in mind the constraint that linearity between variables was the assumption in all cases, the results suggested the following observations:

(1) The quantity of calcium in the feed is the most important variable influencing the quantity of stored phosphorus.

TABLE 20

MULTIPLE LINEAR REGRESSION ANALYSIS - DISC I

VARIABLE	ALL TEST RUNS (a)					RUNS WITHOUT CALCIUM ADDED (b)				
	Mean	Stand Dev.	Corr. Coef.	"t" Value (c) Case A	"t" Value (c) Case B	Mean	Stand. Dev.	Corr. Coef.	"t" Value (c) Case A	"t" Value (c) Case B
Speed (RPM)	41.7	38.9	0.25	1.58		38.1	37.3	0.40	2.77(d)	
Feed COD(mg/l)	347.1	81.2	0.27	0.07		353.8	107.8	0.48	0.10	0.88
Feed N (mg/l)	17.9	8.1	0.28	0.31	2.59(d)	19.3	10.6	0.60	0.12	0.89
Slime VS (%)	90.4	4.2	-0.33	1.11	1.04	92.0	4.9	-0.06	0.99	
Slime C (%)	48.4	9.7	-0.01	0.81		49.7	12.6	0.12	1.00	
Slime N (%)	8.5	2.2	0.77	5.08(d)		8.1	2.9	0.97	10.37(d)	
Feed P (mg/l)	3.8	3.4	0.69	6.23(d)	6.75(d)	2.5	2.2	0.84	0.63	4.05(d)
Feed Ca (mg/l)	43.7	54.9	0.49	5.12(d)	5.93(d)					
Slime P (%) (Dep.Var.)	1.33	0.62				0.99	0.58			

(a) 33 Test runs included
(b) 19 Test runs included
(c) Each case for the independent variables shown.
(d) Significant to the 90% level of confidence

TABLE 21

MULTIPLE LINEAR REGRESSION ANALYSIS - DISC II

VARIABLE	ALL TEST RUNS[a] Mean	Stand Dev.	Corr. Coef.	"t" Value[c] Case A	Case B	RUNS WITHOUT CALCIUM ADDED[b] Mean	Stand Dev.	Corr. Coef.	"t" Value[c] Case A	Case B
Speed (RPM)	41.7	38.9	-0.05	1.98[d]		38.2	37.3	-0.25	1.89[d]	
Feed COD(mg/l)	347.1	81.2	0.32	1.66[d]		353.8	107.8	0.53	-.33	0.57
Feed N(mg/l)	17.9	8.1	0.21	0.09	2.17[d]	19.3	10.5	0.47	0.44	0.65
Slime VS (%)	89.7	2.8	-0.38	2.42[d]	1.96[d]	91.3	2.34	0.19	0.76	
Slime C (%)	47.6	5.3	-0.04	1.68[d]		48.3	6.52	0.15	0.47	
Slime N (%)	9.1	1.1	0.03	1.03		9.2	1.3	0.32	0.91	
Feed P (mg/l)	6.3	3.0	0.31	0.55	0.23	5.12	2.7	0.09	0.62	1.26
Feed Ca(mg/l)	47.1	54.1	0.44	1.59	1.84[d]					
Slime P (%) (Dep. Var.)	1.73	0.42				1.54	0.39			

(a) 33 test runs included
(b) 19 test runs included
(c) Each case for the independent variables shown
(d) Significant to 90% level of confidence

TABLE 22

MULTIPLE LINEAR REGRESSION ANALYSIS - DISC III

	ALL TEST RUNS					RUNS WITHOUT CALCIUM ADDED				
	Mean	Stand Dev.	Corr. Coef.	"t" Value (c) Case A	Case B	Mean	Stand Dev.	Corr. Coef.	"t" Value (c) Case A	Case B
VARIABLE										
Speed (RPM)	41.7	38.9	0.12	0.30		38.2	37.3	-0.18	1.97 (d)	
Feed COD(mg/l)	347.1	81.2	-0.02	0.77		353.8	107.8	0.11	0.17	0.61
Feed N(mg/l)	17.9	8.1	-0.12	0.50	0.72	19.3	10.6	0.05	1.00	0.46
Slime VS (%)	89.4	3.4	-0.58	1.91 (d)	1.69 (d)	91.1	2.8	0.31	0.52	
Slime C (%)	47.3	4.5	-0.31	0.43		48.8	4.9	0.33	1.85 (d)	
Slime N (%)	9.3	1.0	-0.26	0.94		9.7	0.9	0.59	3.32 (d)	
Feed P (mg/l)	10.4	2.1	-0.12	0.48	0.00	10.5	2.5	-0.15	0.44	0.53
Feed Ca(mg/l)	50.7	54.8	0.73	2.84 (d)	3.88 (d)					
Slime P (%) (dep. Var.)	1.82	0.44				1.55	0.25			

(a) 33 test runs included
(b) 19 test runs included
(c) Each case for the independent variable shown
(d) Significant to the 90% level of confidence

TABLE 23

MULTIPLE LINEAR REGRESSION ANALYSIS - DISC IV

VARIABLE	ALL TEST RUNS[a] Mean	Stand Dev.	Corr. Coef.	"t" Value[c] Case A	Case B	RUNS WITHOUT CALCIUM ADDED[b] Mean	Stand Dev.	Corr. Coef.	"t" Value[c] Case A	Case B
Speed (RPM)	41.7	38.9	0.13	0.32		38.2	37.3	-0.32	0.21	
Feed COD(mg/l)	347.1	81.2	-0.08	0.88		353.8	107.8	-0.05	0.25	0.25
Feed N (mg/l)	17.9	8.1	-0.17	0.06	1.91[d]	19.3	10.6	-0.09	0.36	0.29
Slime VS (%)	88.5	3.9	-0.85	5.16[d]	5.84[d]	90.8	2.2	-0.34	1.18	
Slime C (%)	46.2	4.5	-0.25	0.48		46.7	4.9	0.22	0.85	
Slime N (%)	9.2	1.2	-0.39	0.28		9.5	1.3	0.04	0.98	
Feed P (mg/l)	15.6	4.9	-0.19	2.11[d]	2.72[d]	17.3	5.9	0.17	1.34	0.56
Feed Ca (mg/l)	55.4	58.4	0.78	3.30[d]	4.07[d]					
Slime P (%) (Dep.Var.)	1.96	0.60				1.59	0.22			

(a) 33 Test runs included

(b) 19 Test runs included

(c) Each case for the independent variable shown

(d) Significant to the 90% level of confidence

TABLE 24

SUMMARY OF MULTIPLE CORRELATION AND F VALUES BASED ON MULTIPLE LINEAR REGRESSION ANALYSIS OF DATA FROM DISC APPARATUS

DISC	INDEPENDENT VARIABLES INCLUDED	MULTIPLE CORRELATION	"F" VALUE
I	All	0.954	30.46
I	N, P & Ca in feed & % VS in slime	0.893	27.69
I	All except Ca in feed	0.988	64.04
I	COD, N & P in feed	0.846	12.65
II	All	0.741	3.66
II	N, P & Ca in feed & % VS in slime	0.615	4.27*
II	All except Ca in feed	0.730	1.80*
II	COD, N & P in feed	0.600	2.82*
III	All	0.773	4.47
III	N, P & Ca in feed & % VS in slime	0.759	9.50
III	All except Ca in feed	0.837	3.68
III	COD, N & P in feed	0.222	0.26*
IV	All	0.921	16.82
IV	N, P & Ca in feed & % VS in slime	0.917	37.18
IV	All except Ca in feed	0.573	0.77*
IV	COD, N & P in feed	0.188	0.18*

*These values are not significant at 95% level of confidence

Insufficient data are available to show if there is any difference as to the calcium source.

(2) Usually, as the percent volatile solids in the slime increases, the quantity of stored phosphorus decreases. This is the same as saying that as the amount of inorganic calcium phosphate precipitate increases in the slime, the percent volatile solids decreases.

(3) The results are much more random and inconclusive for the runs in which calcium was not added to the feed. This indicates that the biological phenomonen is in a sense more random and unpredictable even under the control conditions of the laboratory. The possibility of running a biological unit with the basic aim of controlling the quantity of phosphorus in the slime appears quite remote.

(4) It appears that the best situation in which it might be possible to predict or control biologically stored phosphorus is when the amount of feed phosphorus is limiting. In other words, feed phosphorus is a much more sensitive parameter when it is biologically limiting. If one compares the mean stored phosphorus in runs without calcium addition for the four discs, the values for discs II, III, and IV are essentially identical and below the values for disc I. It should be recalled that the quantity of phosphorus in the feed to the four discs was varied, with only disc I being phosphorus limiting.

(5) On the basis of the calculated multiple correlation co-efficients and "F" values, it would be safe to state that the percent phosphorus expected in the slime can be predicted from knowing the values of all the independent variables employed, but again it should be stressed that the quantity of calcium in the feed tends to mask all other variables.

(6) Disc speed, the only variable that characterizes a physical feature of the phosphorus uptake process, appears to be a significant factor about one half of the time. At the start of the research project, the suggestion was raised that as the disc speed increases and the resulting slime thickness decreases, the quantity of phosphorus stored per unit weight would tend to increase. By virtue of the fact that both positive and negative correlation co-efficients were obtained for the various disc data, one would be forced to reject this hypothesis outright.

One of the main objectives followed throughout the course of this investigation was to vary operational conditions and to determine what effect these changes had on the quantity of phosphorus stored in the biological slime. It was hoped that one or two set conditions could be

found which encouraged a biota that tended toward a "luxury" uptake of phosphorus. Once this condition or these conditions were identified, an in depth study of them would then follow, including bacteriological analyses, to understand the mechanism of what was going on. Ideally, this understanding could be applied to prototype treatment processes employing bio-slimes on fixed surfaces. For this reason slime was grown under light and dark conditions, with different carbon and nitrogen sources, under varying disc speeds, etc. However, the stored phosphorus never consistently increased above the predictable 1.5 to 2.5 percent range unless it was "forced" with hardness additions. A biological "arrangement" was being sought after which would provide "luxury" phosphorus values in the 3.5 to 5.0 percent range. This could then lead one to a means of enhancing the amount of phosphorus removed by treatment processes using fixed biological slimes. Regretably, this "arrangement" was not found or does not exist.

The Channel Apparatus

As pointed out previously, much of the time devoted to the channel apparatus was spent trying to develop a slime growth that could be effectively used for the investigation. This problem turned out to be much more troublesome than had been anticipated. Once a slime was developed, the analysis of the key constituents of the slime demonstrated that the channel slime growth was similar to the disc growth. For example, the percent volatile solid of the channel slime for some preliminary runs varied from approximately 86 to 91, the percent phosphorus from 1.2 to 2.2 and the percent nitrogen from 8.1 to 10.7. Later, more extensive analysis of the channel slime produced similar results. These values are similar to the ones obtained for a typical disc slime. Thus it can be assumed that the nature and make-up of the two slimes were fairly similar -- a conclusion which would be suggested by a visual comparison of the two slimes as well.

After establishing a set of operating conditions which resulted in a good channel slime growth, a number of simple feed-effluent experiments were conducted. Runs were set up merely to demonstrate that a measureable removal of phosphorus can take place within the length of channel slimes and slopes provided. The only concern at this point was to show that some activity (certainly some of which had to be biological since it is known that phosphorus is incorporated into the living slime matrix) was operative in causing the removal of phosphorus. It was also demonstrated at this time that COD and N were being removed from the feed solution as it passed down the channel slime. The concurrent removal of P, COD and N certainly supports the obvious conclusion that biological activity of the growing slime was mainly responsible for the difference in the feed and effluent constituent concentrations. What was not obvious at this point, however, is whether or not all of the phosphorus removed from the feed solution was needed for metabolic reasons.

As expected, generally the amounts of P, COD and N removed varied in a direct proportion to the length of the channel. Effluent concentra-

tions in almost all cases were lower for the longest channel. The difference was particularly striking when comparing the shortest and the longest channels (18 inches vs 72 inches). Again, though this was expected, it is still not possible to establish if the difference was entirely due to a biological mechanism, at least in the case of phosphorus removal.

The change in the slope of the channel did not appear to have a significant effect on the overall results. If a comparison is made between the "high" slope and the "low" slope results, it appears that the effluent concentration for the latter condition was lower, though thse results are not too conclusive by any means. In other words, time of contact was not a significant variable regardless of the mechanism which is operative in causing the uptake of phosphorus. This may not be unreasonable if one considers that the channel flow condition was estimated to be laminar even under the highest slope condition. Using the form of the Reynolds number as defined by Bird et al. (40), a typical flow rate of 4 ml per minute, and the geometry of the slime channel, a Reynolds number of 21 was estimated. It is suggested by the above reference that "laminar flow without rippling" occurs in a channel when the value is between 4 and 25. The value of the Reynolds number would, of course, be considerably lower under the two flatter slop flow conditions. Under laminar flow conditions the kinetics of passage of phosphorus through the water film is governed by molecular diffusion. In order for molecular diffusion to occur a concentration gradient must set up in the water film directly above the slime interface. The uptake of phosphorus at the interface will result in the formation of this gradient, but it is of little or no consequence whether the gradient results from a biological or physical mechanism. Thus the fact that time of contact was not a significant variable does not give any indication which mechanism is actually operative. All it indicates is that under the three slope conditions employed, phosphorus was taken into the slime at the maximum rate. Had turbulent conditions prevailed, it is likely that the uptake kinetics would would have been increased since the maximum possible concentration of phosphorus is always present at the slime-liquid interface. This is particularly true if the physical mechanism is significant.

It was not until the ultraviolet radiation studies were completed that a clearer insight as to the uptake mechanism was obtained. A series of test runs were conducted in which P, COD and N analyses were compared for the feed and effluent from the channel apparatus, both prior to and following ultraviolet radiation of the slime surface. Under all three slope conditions a significant removal of P, COD and N occurred prior to the ultraviolet exposure. Following exposure to the ultraviolet radiation, removals dropped to zero. Exposure duration was varied from 1 to 72 hours with no appreciable change in results. The characteristics of the slime surface did not appear to be altered by the radiation procedure. Apparently the radiation technique was effective in attenuating the biological activity at the surface of the slime since both the COD and N remained unchanged following passage of the feed solution down the channel. Such was not the case for all the pre-

vious test runs. The fact that there was no phosphorus uptake during these same runs means that this activity is strictly the result of a biological mechanism. There was no evidence of any phosphorus uptake resulting from a physical adsorption on the slime surface.

A second series of test runs was set up to test this thesis further. In this series an initial control run was conducted at the three difficult slopes without any radiation of the slime surface. The results, as before, showed a measureable amount of phosphorus uptake in all cases; the amount being proportional to the length of the channel. The slime surface was then "fed" for 24 hours with dechlorinated tap water which resulted in a starved situation. The surface was fed the test substrate following this starvation period and the results on the effluent were obtained as before. Because of the starved condition, it was theorized that the biological uptake of the phosphorus on the slime surface would be intensified. While a good uptake was obtained in all cases, it was not necessarily an improvement over the initial or control condition, thus, starvation did not markedly enhance the amount of biological phosphorus uptake. Following the test run just described, the slime was again subjected to 24 hours of water feed followed by two hours of ultraviolet radiation of the surface. This feed was continued while the slime surface was subject to the ultraviolet treatment. The test substrate was then fed to the slime and the previously described analyses were conducted on the channel effluents. As before, negligible amounts of phosphorus were removed by the channel slime. Some removal was noted in a few cases, but because COD and N were also removed, it is probable that this removal was due to partial biological activity rather than physical adsorption. Thus in these cases the ultraviolet treatment was not sufficiently effective in inactivating the slime surface. In some of the runs the test procedure was repeated following 24 hours of ultraviolet exposure, but the results were similar to those already described for the 2 hours of exposure.

SECTION XIII

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SECTION XIV

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SECTION XV

APPENDIX

TABLE I

ANALYSIS OF TRICKLING FILTER SLIMES
FROM SIX PLANTS IN THE MILWAUKEE AREA

Date	% Volatile Solids (a) Each Sample	% Volatile Solids (a) Avg.	% Phosphorus (b) Each Sample	% Phosphorus (b) Avg.	% Nitrogen (b) Each Sample	% Nitrogen (b) Avg.	% Carbon (b) Each Sample	% Carbon (b) Avg.
Cedarburg								
Dec. 11, 1969	73.24		2.62		6.15		40.14	
	74.84	74.64	3.56	3.03	6.10	6.12	38.89	40.15
	75.85		2.92				41.42	
Jan. 6, 1970	81.41		1.99		6.38		46.46	
	82.44	82.05	2.04	1.99	6.23	6.40	37.50	41.98
	82.30		1.95		6.60			
April 21, 1970	80.77		2.54		7.35		49.61	
	80.90	80.82	2.38	2.46	7.61	7.46	44.85	46.46
	80.79		2.47		7.42		44.92	
April 28, 1970	80.95		2.32		7.33		38.21	
	80.68	80.44	2.63	2.52	7.47	7.35	40.35	39.28
	79.70		2.61		7.24			
Germantown								
Jan. 6, 1970	69.10		2.28		6.54		28.50	
	75.31	70.82	2.40	2.26	6.61	6.65	30.86	33.24
	68.05		2.10		6.79		40.35	
Hales Corners								
Nov. 11, 1969	79.01		2.00		7.89		45.90	
	82.40	78.64	2.01	2.13	7.94	6.05	43.16	44.85
	74.52		2.38		2.31		45.49	
Nov. 20, 1969	81.72		2.36		7.83		44.36	
	80.17	81.25	2.54	2.40	7.19	7.57	43.76	42.62
	81.85		2.29		7.69		39.75	

TABLE I (continued)

Date	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Phosphorus (b) Each Sample	% Phosphorus (b) Avg.	% Nitrogen (b) Each Sample	% Nitrogen (b) Avg.	% Carbon (b) Each Sample	% Carbon (b) Avg.
Menomonee Falls								
Nov. 11, 1969	79.58		3.03		7.66		36.37	
	79.52	79.57	2.86	2.97	7.52	7.57	36.00	36.34
	79.61		3.02		7.52		36.64	
Nov. 20, 1969	79.81		2.80		7.17		43.69	
	79.75	78.25	2.88	2.84	7.51	7.26	43.97	43.87
	75.18		2.84		7.10		43.95	
Dec. 22, 1969	78.69		2.88		6.95		41.55	
	78.52	78.53	2.79	2.84	6.65	6.65	39.60	38.99
	78.37		2.85		6.36		35.81	
Saukville								
Jan. 6, 1970	80.42		2.34		7.76		45.22	
	82.32	81.70	2.21	2.32	6.62	7.35	47.21	42.00
	82.37		2.40		7.66		33.56	
April 21, 1970	75.28		2.11		7.07		43.35	
	73.99	74.52	2.20	2.20	7.19	7.15	41.81	43.97
	74.28		2.30		7.19		46.76	
April 28, 1970	74.28		2.19		6.62		37.99	
	73.34	73.52	2.39	2.29	6.59	6.62	34.91	38.29
	72.95		2.29		6.66		41.96	
Waukesha								
Nov. 4, 1969			3.08		6.63		46.76	
			3.02	3.10	6.81	6.72	41.62	44.97
			3.21				46.54	
Nov. 11, 1969	74.85		2.75		5.97		35.44	
	76.34	75.78	2.57	2.66	6.90	6.52	40.99	38.73
	76.14		2.65		6.69		39.75	

TABLE I (continued)

Date	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Phosphorus (b) Each Sample	% Phosphorus (b) Avg.	% Nitrogen (b) Each Sample	% Nitrogen (b) Avg.	% Carbon (b) Each Sample	% Carbon (b) Avg.
Nov. 20, 1969	75.21		2.05		6.62		43.35	
	74.53	74.93	2.62	2.47	6.75	6.70	42.22	42.80
	75.05		2.74		6.72		42.82	
Dec. 9, 1969	73.74		2.65		6.05		41.06	
	74.21	73.49	2.80	2.89	6.49	6.25	43.20	45.00
	72.53		3.23		6.22		50.74	
Dec. 22, 1969	71.79		2.60		5.48		39.26	
	73.93	72.86	2.54	2.58	3.22	4.53	41.14	40.91
			2.61		4.90		42.34	
Jan. 9, 1970	72.94		2.76		6.27		28.16	
	72.01	72.64	2.92	2.77	6.42	6.34	46.01	39.19
	72.97		2.64				43.39	
Feb. 14, 1970	75.64		3.29		6.44		47.55	
	71.99	72.10	3.16	3.51	7.06	6.57	45.26	45.22
	68.68		4.07		6.20		42.86	
Feb. 26, 1970	79.27		1.92		7.59		44.36	
	79.55	79.26	3.16	2.71	6.34	7.07	48.26	46.31
	78.97		3.04		7.28			
April 2, 1970	77.35		3.60		6.41		41.29	
	77.11	76.92	3.98	3.81	8.30	7.35	39.90	41.49
	76.29		3.86				43.27	
April 15, 1970	78.17		2.95		6.76		47.66	
	77.71	77.98	2.91	2.84	6.86	6.51	45.04	46.49
	78.06		2.66		5.92		46.76	
April 21, 1970	78.92		2.83		7.28		43.65	
	78.15	78.27	2.41	2.62	6.58	6.71	42.41	44.41
	77.75				6.27		47.17	

TABLE I (continued)

Date	% Volatile Solids		% Phosphorus (b)		% Nitrogen (b)		%Carbon (b)	
	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
April 28, 1970	76.97		2.60		6.93		46.42	
	78.37	68.68	2.91	2.85	7.24	7.17	43.39	44.90
	50.71		3.04		7.35			
May 13, 1970			2.92		5.63		42.52(c)	
			2.83	2.79	5.47	5.64	62.89(c)	62.32(c)
			2.63		5.81		81.56(c)	
June 9, 1970	78.85		2.45		6.97		50.51	
	79.79	79.43	2.31	2.37	7.26	7.13	45.34	48.14
	79.64		2.36		7.15		48.56	
June 22, 1970	76.40		2.42		6.45		69.36	
	76.67	76.35	2.69	2.50	6.62	6.57	45.76	59.60
	75.99		2.40		6.64		63.68	
July 21, 1970	77.71		2.33		6.89		36.82	
	78.91	78.39	1.68	2.40	6.93	6.82	38.62	39.87
	78.54		3.20		6.66		44.18	
August 2, 1970	75.37		2.72		6.84		39.00	
	74.24	76.31	2.79	2.46	6.57	6.73	37.35	40.08
	79.32		1.88		6.78		43.88	
November 13,1970(a)	78.58		2.46		7.85	7.81	43.88	
	78.54	78.67	2.32	2.40	7.76		43.72	42.36
	78.90		2.43				39.49	
January 11, 1971(a)	79.25		2.20		6.72		46.20	
	78.57	79.17	2.57	2.42	7.53	7.15	48.94	47.58
	79.69		2.49		7.19		47.59	
March 11, 1971 (a)	80.90		2.23		7.51		46.01	
	79.48	80.07	2.25	2.24	7.40	7.44	45.81	45.63
	79.82		2.23		7.41		45.06	

TABLE I (continued)

Date	% Volatile Solids		% Phosphorus (b)		% Nitrogen (b)		% Carbon (b)	
	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
May 20, 1971 (a)	81.17		2.21		7.51		45.71	
	80.93	81.12	2.20	2.22	7.62	7.17	44.70	45.50
	81.27		2.25		6.37		46.09	
August 3, 1971 (a)	81.75		2.31		7.74	7.98	43.75	
	82.09	81.89	2.33	2.29	8.23		43.95	43.73
	81.84		2.24				43.50	

(a) The average percent calcium in the last 5 samples were respectively: 11/13 - 3.2%; 1/11 - 2.68%; 3/11 - 3.51%; 5/20 - 1.80%; and 8/3 - 2.82%.

(b) On a total dry weight basis.

(c) Sample contaminated with gasket pieces from blender.

TABLE 2

EFFECT OF REFRIGERATED STORAGE OF WAUKESHA TRICKLING FILTER SLIME ON PHOSPHORUS LEVEL

Sample Identification	Condition	% Phosphorus* Each Sample	Avg.
A3	initial sample untreated	3.40	
A4	initial sample untreated	3.31	3.40
C6	initial sample untreated	3.50	
C7	initial sample washed	3.51	
C9	initial sample washed	3.45	3.46
D3	initial sample washed	3.42	
D10	sample washed after 2 hours	3.24	
E4	sample washed after 2 hours	3.33	3.33
E6	sample washed after 2 hours	3.43	
E8	sample washed in 24 hours	3.71	
E10	sample washed in 24 hours	3.36	3.47
E11	sample washed in 24 hours	3.34	
E13	sample washed after 48 hours	2.97	3.10
E14	sample washed after 48 hours	3.23	
A10	sample washed after 14 days	3.42	
A11	sample washed after 14 days	3.27	3.22
B1	sample washed after 14 days	2.97	
B5	sample washed after 15 days	3.27	
B6	sample washed after 15 days	3.38	3.35
B7	sample washed after 15 days	3.39	

*On total dry weight basis.

TABLE 3
EFFECT OF ROOM TEMPERATURE STORAGE OF ACTUAL TRICKLING FILTER SLIMES ON PHOSPHORUS LEVEL

Sample Identification	Condition	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.
Waukesha - Sample 1					
C3	initial sample untreated	3.08			
C4	initial sample untreated	3.02	3.10		
C5	initial sample untreated	3.21			
C6	initial sample washed	3.12			
C8	initial sample washed	3.29	3.20		
C9	sample washed after 3 hrs.	3.14			
C10	sample washed after 3 hrs.	3.15	3.06		
C11	sample washed after 3 hrs.	2.88			
C12	sample washed after 24 hrs.				
C13	sample washed after 24 hrs.				
E14	sample washed after 24 hrs.				
B8	sample washed after 72 hrs.				
B9	sample washed after 72 hrs.				
B10	sample washed after 72 hrs.				
J12	sample washed after 8 days	3.72			
J13	sample washed after 8 days	3.66	3.72		
H14	sample washed after 8 days	3.77			
L1	sample washed after 15 days	3.57			
L2	sample washed after 15 days	3.43	3.44		
L3	sample washed after 15 days	3.33			
Waukesha - Sample 2					
L1	initial sample untreated	2.75		74.85	
L2	initial sample untreated	2.57	2.66	76.34	75.78
L3	initial sample untreated	2.65		76.14	
L4	initial sample washed	2.81			
L5	initial sample washed	2.74	2.80		
L6	initial sample washed	2.85			
E13	sample washed after 24 hrs.	3.11		75.94	
E14	sample washed after 24 hrs.	3.12	3.09	74.95	75.46
E16	sample washed after 24 hrs.	3.03		75.49	
B4	sample washed after 7 days	2.98		73.71	
B6	sample washed after 7 days	2.83	2.92	72.28	73.39
B7	sample washed after 7 days	2.95		74.18	
J6	sample washed after 14 days	3.29		69.42	
J7	sample washed after 14 days	2.96	3.11	69.77	69.62
J8	sample washed after 14 days	3.07		69.68	

TABLE 3 (continued)

Sample Identification	Condition	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.
Waukesha - Sample 3					
H7	initial sample untreated	2.05		75.21	
H8	initial sample untreated	2.62	2.47	74.53	74.93
H9	Initial sample untreated	2.74		75.05	
L4	sample washed after 24 hrs.	2.57		73.21	
L5	sample washed after 24 hrs.	2.60	2.61	73.29	73.08
L6	sample washed after 24 hrs.	2.65		72.74	
A11	sample washed after 7 days	3.10		70.64	
C13	sample washed after 7 days	2.81	2.94	71.14	70.92
L15	sample washed after 7 days	2.91		70.97	
Menomonee Falls - Sample 1					
H1	initial sample untreated	3.03		79.58	
H2	initial sample untreated	2.86	2.97	79.52	79.57
H3	initial sample untreated	3.02		79.61	
H4	initial sample washed	2.94			
H5	initial sample washed	2.94	2.93		
H6	initial sample washed	2.92			
E9	sample washed after 24 hrs.	3.44		79.22	
E10	sample washed after 24 hrs.	2.88	3.23	79.16	79.22
E11	sample washed after 24 hrs.	3.38		79.28	
A10	sample washed after 7 days	3.62		77.27	
A11	sample washed after 7 days	3.47	3.59	79.67	77.72
C13	sample washed after 7 days	3.69		76.23	
Menomonee Falls - Sample 2					
H6	initial sample untreated	2.80		79.81	
H4	initial sample untreated	2.88	2.84	79.75	78.25
H5	initial sample untreated	2.84		75.18	
J10	sample washed after 24 hrs.	2.76		78.07	
J12	sample washed after 24 hrs.	2.84	2.66	78.81	78.56
J13	sample washed after 24 hrs.	2.39		78.81	
C7	sample washed after 7 days	3.40		75.15	
C8	sample washed after 7 days	3.19	3.28	74.57	69.35
C9	sample washed after 7 days	3.24		58.33	

TABLE 3 (continued)

Sample Identification	Condition	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.
Hales Corners - Sample 1					
D1	initial sample untreated	2.00		79.01	
D2	initial sample untreated	2.01	2.13	82.40	78.64
D3	initial sample untreated	2.38		74.52	
D4	initial sample washed	2.48			
D5	initial sample washed	2.53	2.50		
D6	initial sample washed	2.50			
E2	sample washed after 24 hrs.	2.64		80.89	
E3	sample washed after 24 hrs.	2.65	2.53	81.13	77.96
E8	sample washed after 24 hrs.	2.30		71.85	
C3	sample washed after 7 days	2.73		81.85	
C8	sample washed after 7 days	3.26	2.85	80.29	80.97
C9	sample washed after 7 days	2.57		80.76	
J2	sample washed after 14 days	3.19		74.29	
J4	sample washed after 14 days	2.98	2.94	73.68	73.98
J5	sample washed after 14 days	2.64		73.96	
Hales Corners - Sample 2					
H1	initial sample untreated	2.36		81.72	
H2	initial sample untreated	2.54	2.40	80.17	81.25
H3	initial sample untreated	2.29		81.85	
J1	sample washed after 24 hrs.	2.26		80.87	
J5	sample washed after 24 hrs.	2.26	2.24	80.84	80.91
J9	sample washed after 24 hrs.	2.19		81.01	
C1	sample washed after 7 days	2.43		77.56	
C2	sample washed after 7 days	2.45	2.38	77.93	78.05
C3	sample washed after 7 days	2.27		78.66	

*On total dry weight basis

TABLE 4

EFFECT OF 35°C STORAGE OF ACTUAL TRICKLING FILTER SLIMES ON PHOSPHORUS LEVEL

Sample Identification	Condition	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.
Waukesha - Sample 1					
C4	initial sample, untreated	2.65		73.74	
C5	initial sample untreated	2.80	2.89	74.21	73.49
C6	initial sample untreated	3.23		72.53	
H1	sample washed after 24 hrs.	2.60		71.73	
H2	sample washed after 24 hrs.	2.66	2.65	71.00	71.09
H3	sample washed after 24 hrs.	2.69		70.54	
H4	sample washed after 48 hrs.	3.12		70.71	
H5	sample washed after 48 hrs.	3.05	2.87	69.69	70.25
H6	sample washed after 48 hrs.	2.44		70.35	
H7	sample washed after 72 hrs.	2.69		68.33	
H8	sample washed after 72 hrs.	2.16	2.60	68.67	68.36
H9	sample washed after 72 hrs.	2.95		68.09	
H10	sample washed after 6 days	2.90		66.33	
H11	sample washed after 6 days	2.95	2.96	65.84	66.22
H12	sample washed after 6 days	3.03		66.48	
L10	sample washed after 7 days	3.17		66.22	
L11	sample washed after 7 days	3.19	3.10	66.36	66.21
L12	sample washed after 7 days	2.93		66.04	
L13	sample washed after 14 days	3.63		63.26	
L14	sample washed after 14 days	2.74	3.17	62.10	62.46
L15	sample washed after 14 days	3.15		62.03	
Waukesha - Sample 2					
J1	initial sample untreated	2.60			
J2	initial sample untreated	2.54	2.58	71.79	
J3	initial sample untreated	2.61		73.93	72.86
E10	sample washed after 8 days	3.17		68.38	
E11	sample washed after 8 days	3.18	3.26	67.59	67.88
E12	sample washed after 8 days	3.38		67.68	
Waukesha - Sample 3					
L4	initial sample untreated	2.76		72.94	
L5	initial sample untreated	2.92	2.87	72.01	72.64
L6	initial sample untreated	2.64		72.97	
L16	sample washed after 7 days	3.16		68.17	
L18	sample washed after 7 days	3.30	3.26	70.05	69.78
L20	sample washed after 7 days	3.32		71.12	

TABLE 4 (continued)

Sample Identification	Condition	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.
Saukville					
J4	initial sample untreated	2.34		80.42	
J5	initial sample untreated	2.21	2.32	82.32	81.70
J6	initial sample untreated	2.40		82.37	
J16	sample washed after 7 days	2.01		79.66	
J17	sample washed after 7 days	2.32	2.15	80.22	79.58
J18	sample washed after 7 days	2.11		78.87	
Cedarburg - Sample 1					
E1	initial sample untreated	2.62		73.24	
E2	initial sample untreated	3.56	3.03	74.84	74.64
E3	initial sample untreated	2.92		75.85	
E4	sample washed after 8 days	2.98		69.38	
E5	sample washed after 8 days	2.84	2.89	71.67	69.87
E6	sample washed after 8 days	2.85		68.57	
E7	sample washed after 19 days	3.72		64.74	
E8	sample washed after 19 days	3.78	3.63	64.89	64.69
E9	sample washed after 19 days	3.38		64.43	
Cedarburg - Sample 2					
D4	initial sample untreated	1.99		81.41	
D5	initial sample untreated	2.04	1.99	82.44	82.05
D6	initial sample untreated	1.95		82.30	
D16	sample washed after 7 days	2.38		79.01	
D17	sample washed after 7 days	1.96	2.21	78.28	78.53
D18	sample washed after 7 days	2.28		78.29	
Germantown					
H4	initial sample untreated	2.28		69.10	
H5	initial sample untreated	2.40	2.26	75.31	70.82
H6	initial sample untreated	2.10		68.05	
H16	sample washed after 7 days	2.71		68.80	
H17	sample washed after 7 days	2.58	2.79	69.66	69.00
H18	sample washed after 7 days	3.08		68.53	
Menomonee Falls					
H1	initial sample untreated	2.88		78.69	
H2	initial sample untreated	2.79	2.84	78.52	78.53
H3	initial sample untreated	2.85		78.37	
D10	sample washed after 8 days	3.34		74.94	
D11	sample washed after 8 days	3.63	3.42	75.56	75.27
D12	sample washed after 8 days	3.28		75.30	

*On total dry weight basis

TABLE 5

EFFECT OF ANAEROBIC STORAGE AT 35°C OF WAUKESHA PLANT SLIME ON PHOSPHORUS LEVELS (RUN NO. 1)

Time	Supernatant Phosphorus (mg/l) Each Sample	Avg.	Slime Phosphorus* (%) Each Sample	Avg.	% Volatile Solids Each Sample	Avg.
Initially			1.92[1] 3.16[1] 3.04[1]	2.71[1]	79.27[1] 79.55[1] 78.97[1]	79.26[1]
1 day	13.98[1] 15.60[1]	14.79[1]				
2 days	86.50[1]	86.50[1]				
4 days	190.0[1] 170.0[1] 159.0[1] 149.0[1]	167.0[1]				
5 days	167.0[1] 188.0[1] 179.0[1] 175.0[1] 154.0[1]	152.6[1]				
6 days	205.0[1] 200.0[1] 191.0[1] 213.0[1] 174.0[1] 166.0[2] 183.0[2] 174.0[2] 185.0[2] 184.0[2] 176.0[2] 180.0[2]	191.5[1] 180.3[2]	2.77[1] 2.88[1] 2.88[1]	2.84[1]	76.96[1] 77.80[1] 77.82[1]	77.53[1]
8 days	176.0[2] 220.0[2] 213.0[2] 213.0[2]	205.5[2]				
9 days	174.0[2] 150.0[2]	162.0[2]				
11 days	180.0[2] 171.0[2]	175.5[2]				
12 days	200.0[2] 200.0[2]	200.0[2]				

TABLE 5 (continued)

Time	Supernatant Phosphorus (mg/l) Each Sample	Avg.	Slime Phosphorus* (%) Each Sample	Avg.	% Volatile Solids Each Sample	Avg.
13 days	141.0[2] 155.0[2]	148.0[2]				
15 days	192.0[2] 188.0[2]	190.0[2]				
16 days	164.0[2] 164.0[2] 151.0[2]	159.7[2]				
18 days	180.0[2] 169.0[2]	174.5[2]				
21 days	200.0[2] 200.0[2]	200.0[2]				
22 days			4.29[2] 3.71[2] 3.93[2]	3.98[2]	71.34[2] 71.70[2] 71.52[2]	71.52[2]
23 days	151.0[2]	151.0[2]				
25 days	170.0[2]	170.0[2]				
26 days	125.0[2]	125.0[2]				

*On total dry weight basis
(1) First flask
(2) Second flask

TABLE 6

EFFECT OF ANAEROBIC STORAGE AT 35°C
OF WAUKESHA PLANT SLIME ON PHOSPHORUS LEVELS
(RUN NO. 2)

Time	Supernatant Phosphorus (mg/l) Each Sample	Avg.	Slime Phosphorus* (%) Each Sample	Avg.	% Volatile Solids Each Sample	Avg.
initially	7.91_2^1 8.80_3^- 10.06_4 0.68_5 0.83^5		3.60_1^1 3.98^1 3.86^1	3.81^1	77.35^1 77.11^1 76.29^1	76.92^1
1 day	91.76_2^1 83.51_3^2 89.15_4^3 83.77_5^4 81.02^5					
4 days	209.76^1 151.72_2^1 160.56_2^- 159.20_2^- 148.68^2	180.74^1 156.15^2				
5 days			3.48^1 2.98^1 2.95^1	3.14^1	69.15^1 70.19^1 69.54^1	69.63^1
11 days	203.00^2 212.56_2^2 189.48^2	201.68^2	3.02_2^2 3.29_2^- 2.93^2	3.08^2	72.74_2^2 72.80_2^2 72.36^2	72.63^2
12 days	191.56_3^3 181.36_3^3 188.96^3	187.29^3				
14 days	175.00_3^3 188.48_3^3 183.36_3^3 180.88_4^4 181.36_4^4 175.48^4	182.28^3 179.24^4	3.58_3^3 3.54_3^3 3.18^3	3.43^3	69.28_3^3 68.97_3^3 69.07^3	69.11^3
22 days	127.80_4^4 121.10_4^4 134.60_5^5 113.10_5^5 127.80_5^5 140.10^5	127.83^4 127.00^5	3.39_4^4 4.00_4^4 3.96^4	3.78^4	64.42_4^4 65.62_4^4 65.03^4	65.02^4

TABLE 6 (continued)

Time	Supernatant Phosphorus (mg/l) Each Sample	Avg.	Slime Phosphorus* (%) Each Sample	Avg.	% Volatile Solids Each Sample	Avg.
25 days	121.10^{5}		3.97^{5}		64.10^{5}	
	125.80^{5}	124.90^{5}	3.79^{5}	3.82^{5}	63.53^{5}	63.13^{5}
	127.80^{5}		3.70^{5}		61.75^{5}	

*On total dry weight basis
(1) (2) (3) (4) and (5) refer to flask number

TABLE 7

EFFECT OF ANAEROBIC STORAGE AT 35°C
OF LABORATORY SLIME ON PHOSPHORUS LEVELS

Time	Supernatant Phosphorus (mg/l) Each Sample	Avg.	Slime Phosphorus * (%) Each Sample	Avg.	% Volatile Solids Each Sample	Avg.
initially	0.00		0.76		95.63	
	0.00	0.00	0.59	0.72	94.85	95.53
	0.00		0.80		96.10	
1 day	5.12					
	0.00	2.28				
	1.73					
3 days	2.07	2.07				
4 days	12.72	12.72				
13 days	4.82		0.41		99.07	
	5.02	4.92	0.40	0.40	96.91	98.22
			0.40		98.67	

*On percent dry weight basis

TABLE 8

EFFECT OF ANAEROBIC STORAGE AT 35°C OF WAUKESHA PLANT SLIME ON PHOSPHORUS LEVELS

Time	Flask	Supernatant Phosphorus (mg) Each Sample	Supernatant Phosphorus (mg) Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Solids Each Sample	% Solids Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
initial[$]	1	0.796		2.42		7.07		76.40		69.36		6.45	
	2	1.454		2.69	2.50	7.06	7.09	76.67	76.35	45.76	59.66	6.62	6.57
	3	1.154		2.40		7.14		75.99		63.68		6.64	
	4	1.633											
	5	1.190											
1 day	1	18.44	18.44	2.17				75.73		43.76	44.04	6.04	
	2	20.03	20.03	2.25	2.18			74.87	75.39	44.32		6.15	6.06
				2.18				75.58				5.98	
2 days	2	44.32		2.15				74.29[#]		44.89		5.70	
		43.10	43.50	2.07[#]	2.11			44.51[#]	73.94	39.83	41.95	5.67	5.71
		43.09		2.60[#]				73.60		41.14		5.75	
	3	47.07											
		48.26	47.81										
		48.11											
3 days	3	56.97		2.13				71.79		39.92		5.51	5.52
		55.30	58.09	2.23	2.13			72.54	72.11	36.75	39.67	5.52	
		62.01		2.02				72.00		42.39			
	4	58.60											
		59.09	59.85										
		61.87											

TABLE 8 (continued)

Time	Flask	Supernatant Phosphorus (mg) Each Sample	Supernatant Phosphorus (mg) Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Solids Each Sample	% Solids Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
4 days	4	61.70		2.10				72.19		38.00	35.18	5.42	
		62.38	62.96	2.17	2.15			72.50	72.53	32.36		5.42	5.25
		64.81		2.17				72.90				4.92	
	5	61.13	62.15										
		63.50											
		61.82											
7 days	5	67.08		2.04	2.04			72.05		33.26	34.93	5.08	5.22
		67.08	68.71	2.03				71.37	71.15	36.60		5.35	
		71.97						70.04					

*On a percent dry weight basis
#Problem with analysis procedures - not used in average calculation
$Average present calcium in the original sample was 2.78%

TABLE 9

EFFECT OF ANAEROBIC STORAGE AT 35°C OF WAUKESHA PLANT SLIME ON PHOSPHORUS LEVELS

Time	Flask	Supernatant Phosphorus (mg) Each Sample	Avg.	% Phosphorus* Each Sample	Avg.	% Solids Each Sample	Avg.	% Volatile Solids Each Sample	Avg.	% Carbon Each Sample	Avg.	% Nitrogen Each Sample	Avg.
initial	1	1.159		2.33		6.64		77.71		36.82		6.89	
	2	1.144		1.68	2.40	6.49	6.56	78.91	78.39	38.62	39.87	6.93	6.82
	3	0.7128		3.20		6.56		78.54		44.18		6.66	
	4	2.214											
1 day	1	19.256	19.52										
		19.787											
2 days	1	36.35											
		34.48	34.51										
		32.70											
3 days	1	44.68											
		44.68	44.06										
		42.83											
6 days	1	59.98											
		59.98	60.66										
		62.01											
7 days	1	60.14		1.73				76.12		45.04		5.89	
		59.65	59.76	1.81	1.82			75.98	76.13	46.84	44.65	5.79	5.71
		59.49		1.94				76.28		42.08		5.45	
	2	62.57											
		59.89	62.04										
		63.81											

TABLE 9 (continued)

Time	Flask	Supernatant Phosphorus (mg) Each Sample	Avg.	% Phosphorus* Each Sample	Avg.	% Solids Each Sample	Avg.	% Volatile Solids Each Sample	Avg.	% Carbon Each Sample	Avg.	% Nitrogen Each Sample	Avg.
8 days	2	66.27											
		65.19	65.66										
		65.51											
9 days	2	57.05											
		60.89	58.72										
		58.25											
12 days	2	57.83											
		57.37	57.86										
		58.91											
13 days	2	58.94		1.64				73.53		44.96		5.98	
		61.55	56.75	2.00	2.22			74.19	74.17	46.54	45.80	6.56	6.27
		49.75		3.02				74.80		45.90			
	3	62.09											
		60.71	59.53										
		55.85											
14 days	3	53.59											
		53.01	55.13										
		58.88											
15 days	3	59.24											
		60.71	61.04										
		63.17											
30 days	3	51.58		2.39	2.36			70.72		40.58		4.50	
		50.06	51.22	2.33				70.98	70.80	33.90	40.05	5.78	5.32
		52.01						70.69		45.68		5.69	
	4	48.92											
		49.60	50.72										
		53.64											

TABLE 9 (continued)

Time	Flask	Supernatant Phosphorus (mg) Each Sample	Supernatant Phosphorus (mg) Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Solids Each Sample	% Solids Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
6 weeks	4	50.96		2.31				69.80		42.71		6.09	
		48.65	50.98	2.76	2.61			69.34	69.66	43.05	42.35	5.65	5.84
		53.32		2.75				69.84		41.29		5.78	

*On a dry weight basis

TABLE IC

EFFECT OF ANAEROBIC STORAGE AT 35°C OF LABORATORY SLIME ON PHOSPHORUS LEVELS

Time	Disc	Supernatant Phosphorus (mg) Each Sample	Supernatant Phosphorus (mg) Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Solids Each Sample	% Solids Avg.	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
initial	I			1.50	1.50								
	II			1.42	1.40								
	III			1.38									
				1.53	1.50								
	IV			1.47									
	Comp.	---	---	1.54	1.54								
				1.38		1.74				49.54		9.66	
				1.17	1.30	1.78	1.74			51.22	50.42	9.83	9.70
				1.34		1.71				50.51		9.63	
1 day#		11.048											
		11.087	11.437										
		12.176											
2 days		14.109											
		14.840	14.596										
		14.840											
3 days		15.179											
		15.676	15.493										
		15.626											
4 days		16.429											
		15.725	15.959										
		15.725											
7 days		12.613	14.068										
		15.523											

TABLE 10(continued)

Time Disc	Supernatant Phosphorus (mg) Each Sample	Avg.	% Phosphorus* Each Sample	Avg.	% Solids Each Sample	Avg.	% Volatile Solids Each Sample	Avg.	% Carbon Each Sample	Avg.	% Nitrogen Each Sample	Avg.
8 days#	19.154											
	17.542	18.214										
	17.947											
9 days	17.363											
	17.789	17.539										
	17.466											
10 days	17.363											
	18.002	17.592										
	17.412											
13 days	17.734	17.286										
	16.839											
14 days	16.533											
	16.429	16.722										
	17.204											
15 days	19.208											
	19.099	18.877										
	18.324											
16 days	17.521											
	18.056	18.412										
	19.661											
31 days	20.240											
	18.002	18.606										
	17.576											
6 wk-1 day	14.889		0.88				97.95					
	15.921	15.411	0.80	0.83			95.79	97.44				
	15.424		0.82				98.57					

*Percent dry weight basis
#Remainder with composite sample

TABLE II

TOTAL HARDNESS OF
TRICKLING FILTER SLIMES

Slime Sample	Condition	% Hardness# as $CaCO_3$
Waukesha (Sample 1-Table 4)	initial	8.3
	24 hours	11.4
	7 days	13.1
	14 days	9.8
Waukesha (Sample 2-Table 4)	initial	12.0
	8 days	12.3
Waukesha (Table 5)	initial	9.6*
	6 days	10.0*
	22 days	14.57*
Cedarburg (Sample 1-Table 4)	initial	11.97
	8 days	12.0
Menomonee Falls (Table 4)	initial	16.1
	8 days	14.2
Laboratory Slime from Settling Cone	initial, Disc III	1.02*
	initial, Disc IV	1.17*

*Slime digested with HCl. All the other samples digested with perchloric-nitric acid mixture according to Standard Methods.

#After digesting a known weight of oven dried slime, the sample was solublized to a convenient volume, usually 50 ml. The hardness concentration in this volume was determined and expressed as mg/l $CaCO_3$. This concentration was then expressed as a weight and related to the original weight of the dried slime sample, hence the unit, %Hardness as $CaCO_3$.

TABLE 12

LOG OF ALL TEST RUNS CONDUCTED WITH DISC APPARATUS

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P.(mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
1	1-14-70	1	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	Same yield; I-yellow; II, III-white; IV-pink; I-thickest growth
2	1-21-70	1	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	I-pink; II-lt. pink; III, IV-cream; enough growth for duplicates on VS, P,C,N; I-thickest growth
3	1-30-70	1	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	I, II, III, IV-creamy white; III-thickest growth; IV-most cohesive
4	2-11-70	1	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	I-white; II-creamy white; III, IV-creamy white with little green; IV-most cohesive; I-40 ml; II-45 ml; III-80 ml; IV-50 ml(Slime yields)
1-A-S-1	2-26-70	1	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	I, II, III-white; IV-dark cream; II-most cohesive
1-B-S-1	3-31-70	1	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 2, 24		No	All white; I-most cohesive; II-very fragile

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
I-A-S-100	4-24-70	100	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	All units cohesive; very thin growth; II-very pale green algal growth at edge; III-grey-brown; IV-black specks; II & IV-granular
I-B-S-100	5-8-70	100	Soft	Glucose 300	NH_4Cl 12	.24, 2.4, 12, 24		No	I-cream; II, IV-yellowish with some algae; III-cream with some algae; IV-most cohesive; II-thickest growth
I-A-S-50	5-22-70	50	Soft	Glucose 300	NH_4Cl 12	.24,2.4, 12, 24		No	I-white with faint pink; II-yellow with traces of algae; III-yellow-green; IV-yellow; all very fragile; II, III-granular IV-thickest, but a lot broken off.
I-B-S-50	6-5-70	50	Soft	Glucose 500	NH_4Cl 12	.24,2.4, 12, 24		No	I-white with light pink; II, IV-creamy white to yellow with green around edges; III-pale green with dark green at edges; II, III- granular; II, IV-slough off; I-35 ml; II-80 ml; III-25 ml; IV-50 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
II-A-S-25	6-18-70	25	Soft	Glucose, Nutrient Broth; Yeast Extract 330	Glucose; Nutrient Broth; Yeast Extract 22-24	3, 6, 9, 12 + from feed		No	I-pinkish yellow; II, III, IV-yellow with green algae; I, III-feathery; II-most cohesive; I, III, IV-partly sloughed off; I-25 ml; II-75 ml; III-25 ml; IV-60 ml
II-A-S-50	7-1-70	50	Soft	Glucose; Nutrient Broth; Yeast Extract 330	Glucose; Nutrient Broth; Yeast Extract 22-24	3,6,9, 12 + feed		No	I-orange; II, III, IV-yellow orange with algae growth; I-feathery and filamentous; I-50 ml; II-100 ml; III-50 ml; IV-75 ml
II-A-S-100	7-13-70	100	Soft	Glucose; Nutrient Broth; Yeast Extract 330	Glucose; Nutrient Broth Yeast Extract 22-24	3,6,9, 12 + feed		No	I-pink; II, III, IV-light pink with some algae; very thin growth; small yield; I, IV,-10 ml; II, III-25 ml.
II-B-S-25	7-20-70	25	Soft	Glucose; Nutrient Broth; Yeast Extract 330	Glucose; Nutrient Broth; Yeast Extract 22-24	3,6,9, 12 + feed		No	I-pink; II, III-pinkish orange with small amount algae; IV-yellow with little algae; I-25 ml; II, III-50 ml; IV-30 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
III-A-S-25	7-28-70	25	Soft	Glucose Nutrient Broth; Yeast Extract 660	Glucose Nutrient Broth; Yeast Extract 40-45	3,6,9, 12 + feed		No	All creamy yellow; feathery; I-cohesive; II, III, IV-slough off; II, IV-slimy; I, II-50 ml; III-40 ml; IV-60 ml
III-B-S-25	8-5-70	25	Soft	Glucose; Nutrient Broth; Yeast Extract 660	Glucose; Nutrient Broth; Yeast Extract 40-45	3,6,9, 12 + feed		No	All creamy yellow-orange; II, III, IV-like peach-skin in thin part; I, III-ropey in thick part; I-40 ml; II-55-60 ml; III-30 ml; IV-50 ml; 2 different thicknesses due to motor stopping over-night
III-A-S-100	8-21-70	100	Soft	Glucose; Nutrient Broth; Yeast Extract 660	Glucose; Nutrient Broth; Yeast Extract 40-45	3,6,9, 12 + feed		No	I, II, III-rust color; IV-rose color; very blotchy, large chunks, broken off; thick and thin sections on each disc; I-35 ml; II-55 ml; III-30 ml; IV-50 ml
IV-A-S-25	9-4-70	25	Soft	Milk 320	Milk 14-15	from milk only	from milk only	No	I,II,III-peach; IV-cream; I,IV-variable thickness; II,III-uniform thickness; I, IV-stringy; I-tenacious; II,III-firm slime; IV-fragile

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon CO_2 (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
V-A-S-25	9-11-70	25	Soft	Milk 320	Milk 14-15	3,6,9, 12 + feed	from milk only	No	I-peach; II,III,IV-cream; I-uniform thickness; II,III,IV-irregular thickness; I-cohesive; IV-very small specks of green; I-80 ml; II,IV-100 ml; III-70 ml
V-A-S-100	9-25-70	100	Soft	Milk 320	Milk 14-15	3,6,9, 12 + feed	from milk only	No	I,II,IV-cream; III-reddish; I,III-80 ml; II-100 ml; IV-70 ml
V-B-S-100	10-9-70	100	Soft	Milk 320	Milk 14-15	3,6,9, 12 + feed	from milk only	No	I,II,III-tannish pink slime; very tenacious; IV-yellow-green and fragile
VI-A-H-25	10-29-70	25	Hard	Milk 320	Milk 14-15	3,6,9, 12 + feed	$CaCl_2$ 100 + milk + H_2O	No	All orange; rough textured; different from all other runs; I,II,III-tenacious, dry-consistency of squash; III,IV-gritty; I-55 ml; II-80 ml; III,IV-75 ml
VI-B-H-25	11-13-70	25	Hard	Milk 320	Milk 14-15	3,6,9, 12 + feed	$CaCl_2$ 100 + milk + H_2O	No	I,II,III-variegated, light and dark brown; IV-same with green; I,II,III-tenacious; II,III-dry; III-gritty at edge; IV-gritty all over; I-75 ml; II-90 ml; III-50 ml; IV-85 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
VI-A-H-100	11-25-70	100	Hard	Milk 320	Milk 14-15	3,6,9, 12 + feed	$CaCl_2$ 100 + milk + H_2O	No	IV-light pink; I-dry; all very tenacious; III,IV-come off in sheets; I-70 ml; II-75 ml; III-65 ml; IV-55 ml
VI-B-H-100	12-9-70	100	Hard	Milk 320	Milk 14-15	3,6,9, 12 + feed	$CaCl_2$ 100 + milk + H_2O	No	I,III-dark yellow-brown; II-light yellow-brown; IV-yellow-orange with brown blotches; all very tenacious; I,II,III-very dry; I-60 ml; II-50 ml; III,IV-70 ml
VII-A-S-25	12-22-70	25	Soft	Milk 320	Milk 14-15	9 + feed	$CaCl_2$ 0,25,50, 100 + milk	No	I-cream-darkest of four; all good thick growths; II,III,IV-all with a lot sloughed off and lumpy; I-jellylike consistency; II,III,IV-watery consistency; I,IV-250 ml; II,III-200 ml
VII-B-S-25	1-11-71	25	Soft	Milk 320	Milk 14-15	9 + feed	$CaCl_2$ 0,25,50, 100 + milk	No	I-beige; II-orange (darkest); III-between I and II; IV-yellow; II and IV-very cohesive; I and III-less cohesive; I-225 ml; II-125 ml; III-90 ml; IV-50 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
VII-A-S-100	1-29-71	100	Soft	Milk 320	Milk 14-15	9 + feed	$CaCl_2$ 0,25,50 100 + milk	No	I-light yellow; II-yellow; III-orange-yellow; IV-orange with green; I-smooth texture; II,III-texture not consistent; IV-pumpkin-like consistency; all very cohesive; I-20 ml; II,IV-25 ml; III-30 ml
VII-A-S-10	2-12-71	10	Soft	Milk 320	Milk 14-15	9 + feed	$CaCl_2$ 0,25,50, 100 + milk	No	I-white; I,III-yellow-beige; IV-peachy; I-soft and smooth-not tenacious; II-thick and thin-tenacious where thin; not where thick; III-lumpy, tenacious; IV-tenacious; comes off in sheet-skinlike; I-100 ml; II,III-120 ml; IV-60 ml
VIII-A-H-10	2-24-71	10	Hard	Milk 320	Milk 14-15	0,3,6, 12 + feed	$Ca(OH)_2$ 50 + milk + H_2O	No	I-peach; II,III,IV-yellowish; I-smoothest-but small bumps; II-bumps most prominent; III,IV-pebbly appearance; II,IV-peels off like skin; all cohesive; I,III-175 ml; II-90 ml; IV-120 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l) Ca	Light*	Remarks$
VIII-B-H-10	3-10-71	10	Hard	Milk 320	Milk 14-15	0,3,6, 12 + feed	$Ca(OH)_2$ 50 + milk + H_2O	No	I-yellow-brown; II-cream; III-grey-green; I-uniform thickness; others have sloughed off patches; I-most tenacious; IV-slimy; I-100 ml; II,III-175 ml; IV-150 ml
IX_L-A-H-10	3-26-71	10	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	Milk + H_2O	Yes	I-green particies in clear or tannish matrix; II,III,IV-tan on green; tan washes off; IV-tan more stringy; II-bumpy; under it is tenacious; I-50 ml; II,III-70 ml; IV-60 ml
IX_L-B-H-10	4-14-71	10	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	Milk + H_2O	Yes	I-grey-white over green with reddish brown blotches in green; II-green with very few red-brown blotches; III-grey-white over green with very little brown; IV-variegated green with brown bumps; IV-most tenacious; I-120 ml; II,IV-100 ml; III-150 ml
IX_L-A-H-50	4-30-71	50	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	Milk + H_2O	Yes	All dark green with no white; I-least bumpy; IV-most bumpy; IV-driest and most cohesive; I-110 ml; II-120 ml; III-120 ml; IV-100 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l) Ca	Light*	Remarks$
IX_L-A-H-100	5-19-71	100	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	Milk + H_2O	Yes	I-light tan-green over dark green; II,III-bright green blotches over grey-green; IV-finely mottled-light and dark green; I-dry; II,III-more wet; IV-thick and lumpy-consistency of thick milk shake, very tenacious; I-150 ml; II-120 ml; III-90 ml; IV-60 ml
X_L-A-H-10	6-4-71	10	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	$CaCl_2$ 100 + milk + H_2O	Yes	All four light green filamentous growth over inner 2/3 of discs; IV-most cohesive, then I - III - II; I-smooth; II-more fluid; IV-dry-gritty; I-175 ml; II-140 ml, III-110 ml; IV-90 ml
X_L-A-H-100	6-23-71	100	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	$CaCl_2$ 100 + milk + H_2O	Yes	Underlayers-green; tenacious; upper layer lighter-not very tenacious; I and II-pebbly looking; I-100 ml; II-105 ml; III-95 ml; IV-60 ml

TABLE 12 (continued)

Run	Date	Speed RPM	Water#	Carbon COD (mg/l)	Nitrogen N (mg/l)	Phosphorus Na_2HPO_4 P (mg/l)	Calcium (mg/l)Ca	Light*	Remarks$
$VIII_L$-A-H-10	7-2-71	10	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	CaO 50+ milk + H_2O	Yes	I-brown-green; II,III, IV-green; I-most tenacious, II and III-least tenacious; I and IV-filamentous growth moves about when washed; II and III-top layer washes off; I-like very thick taffy; II and IV-like taffy; III-soft
$VIII_L$-A-H-100	7-19-71	100	Hard	Milk 320	Milk 14-15	0,3,6, 12 + milk	CaO 50+ milk+ H_2O	Yes	II-most tenacious; not moved with H_2O; I and III-move with H_2O wash; IV-lightest green; I-yellow-green with brown; II-dark yellow-green with dark green bumps; III-light green in middle, dark green at edges; I,II,III-consistency of baby food.

# Soft = Milwaukee tap Zeolite softened
Hard = Milwaukee tap

* Plant light on continuously over disc apparatus

$ Slime yield in ml reported where applicable

TABLE 13

ANALYSIS OF DISC SLIMES AT VARYING SPEEDS
AND DIFFERENT GROWING CONDITIONS

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
Jan. 14, 1970	I	94.68	94.68	0.31	0.31	51.00	51.00	4.06	4.06
X-A-S-1#	II	91.95	91.95	1.80	1.80	58.91	58.91	7.39	7.39
	III	91.78	91.78	1.81	1.81	53.66	53.66	8.44	8.44
	IV	93.72	93.72	1.51	1.51	51.67	51.67	5.89	5.89
Jan. 21, 1970	I	94.09		0.22		45.72		3.60	
X-B-S-1#		96.76	95.42	0.22	0.22	45.34	45.53	3.82	3.71
	II	91.33		1.82		28.05		9.62	
		90.44	90.88	1.84	1.83	44.47	36.71	9.81	9.71
	III	95.41		2.10		51.79		11.18	
		89.29	92.35	2.10	2.10	47.70	49.74	11.07	11.12
	IV	90.92		1.78		48.11		9.98	
		90.10	90.55	1.85	1.81	33.34	40.72	9.83	9.90
Jan. 30, 1970	I	96.70		0.11		23.10		4.17	
X-C-S-1#		93.67	95.46	0.11	0.11	24.97	25.26	4.15	4.07
		96.00		0.11		27.71		3.90	
	II	94.59		1.15		41.44		7.02	
		94.21	94.07	1.09	1.12	40.82	41.72	5.79	6.44
		93.41		1.12		42.90		6.52	
	III	93.76		1.20		39.04		8.75	
		92.25	92.76	1.25	1.17	44.62	41.45	8.55	8.63
		92.27		1.07		40.69		8.60	
	IV	91.17		1.22		46.12		8.77	
		89.73	90.51	1.23	1.25	47.51	42.84	8.44	8.69
		90.62		1.30		34.09		8.86	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
Feb. 11, 1970 X-D-S-1#	I	95.80	95.80	0.33 0.46 0.37	0.39	56.29 45.42	50.85	4.64 4.83 4.64	4.70
	II	92.00	92.00	1.42 1.64 1.52	1.53	53.47 46.27	49.87	8.89 8.29 8.84	8.67
	III	90.34	90.34	1.68 1.15 2.17	1.67	50.21 46.50 44.59	47.10	9.37 9.22 9.52	9.37
	IV	91.72	91.72	1.54 1.72 1.40	1.55	49.69 48.52	49.10	9.99 9.69 9.82	9.83
Feb. 26, 1970 I-A-S-1#	I	73.91	73.19	0.31 0.30 0.33	0.31	83.21 88.20	85.70	4.78 4.45	4.61
	II	84.53	84.53	1.31 1.27 1.51	1.29	64.31	64.31	6.52	6.52
	III	83.01	83.01	0.76 1.04	1.10	56.74 49.27	53.00	7.12 7.13	7.13
	IV	87.50	87.50	1.87 1.94 2.32	2.04	54.90	54.90	8.08	8.08
March 31, 1970 I-B-S-1	All+	95.63 94.85 96.10	95.53	0.76 0.58 0.79	0.71	39.60 49.76 43.39	44.25	4.48 4.54 4.62	4.55
April 2, 1970**	I			2.38	2.38				
	II			1.92	1.92				
	III	94.71 93.75	94.23	1.87 1.88 1.70	1.82	43.65	43.65	8.89	8.89

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
	IV	95.83		1.39		43.99		8.51	
		96.51	96.17	1.23	1.31		43.99		8.51
April 24, 1970	I	97.62	97.62	0.78	0.78				
I-A-S-100	II	95.07	95.07	1.26	1.30				
				1.35					
	III	85.96	85.96	1.57	1.57				
	IV	93.89	93.89	1.36	1.36				
May 8, 1970	I	97.39	97.39	0.27	0.27				
I-B-S-100	II	90.94	91.55	1.53	1.53	45.07	46.46	8.58	
		92.16		1.52		47.85		8.83	8.72
								8.76	
	III	94.59	94.59						
	IV	89.94	90.27	1.50		56.17	53.73	8.20	8.19
		90.59		1.49	1.47	51.30		8.18	
				1.43					
						20.32		5.94	
May 22, 1970	I	97.94		0.51		39.00	28.97	5.30	5.54
I-A-S-50#		97.62	97.98	0.26	0.35	27.60		5.39	
		98.38		0.28		33.11		8.73	
	II	93.62		1.75		32.14	39.66	7.84	8.18
		93.66	93.71	1.60	1.69	53.74		7.97	
		93.84		1.72		39.49	39.49	9.06	9.06
	III	95.06	95.73	1.43					
		96.39		1.36	1.42				
				1.46					
	IV	95.27		1.52		29.62		9.47	
		95.31	94.77	1.50	1.55	33.00	33.47	8.10	9.03
		93.72		1.64		37.80		9.51	
						41.74		5.53	
June 5, 1970	I	96.34		0.28		51.08	46.41	4.26	4.73
I-B-S-50#		94.50	93.99	0.44	0.32			4.40	
		91.14		0.25					

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
	II	89.32		1.61		40.58		9.33	
		89.86	89.60	1.55	1.59	59.89	49.32	9.30	9.23
		89.61		1.60		47.51		9.05	
	III	90.26		1.60		49.72		9.36	9.20
		89.55	89.70	1.49	1.59	47.44	51.76	9.03	
		89.29		1.68		58.01			
	IV	87.50		1.99		43.28		8.96	
		88.60	88.11	1.82	1.85	48.34	42.09	8.82	8.77
		88.22		1.75		34.65		8.52	
June 18, 1970 II-A-S-25#	I	90.58		1.70		31.54		11.50	
		92.67	91.28	1.95	1.80	51.79	47.64	11.32	11.42
		90.58		1.74		59.59		11.44	
	II	90.19		1.66		48.98		10.69	
		91.80	91.21	1.71	1.69		47.22	10.24	10.67
		91.64		1.70		45.45		10.59	
	III	92.77		1.60		57.15		10.19	
		91.43	92.04	1.77	1.66	56.29	53.80	10.33	10.18
		91.91		1.60		47.96		10.01	
	IV	89.18		1.90	1.92	33.68		10.77	
		88.76	89.47	1.94		51.41	47.25	11.05	10.69
		90.46				56.62		10.25	
July 1, 1970 II-A-S-50#	I	91.40		1.47		43.43		10.00	
		91.03	90.97	1.28	1.37	42.56	44.48	10.03	9.98
		90.49		1.38		47.44		9.91	
	II	89.25		1.34		41.21	43.69	9.53	
		89.67	89.78	1.36	1.37	46.16		9.74	9.76
		90.43		1.42				10.02	
	III	89.19	89.20	1.36		35.29		10.01	
		89.20		1.59	1.44	37.61	38.78	10.32	10.18
				1.38		43.43		10.22	
	IV	87.87	89.04	1.59		46.84		9.82	
		90.22		1.58	1.50	39.86	45.11	10.44	9.97
				1.35		48.63		9.66	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
July 13, 1970	I	91.43	92.12	1.06		49.09	68.99	9.38	9.74
II-A-S-100#		92.82		1.22	1.19	88.88		10.10	
				1.29					
	II	93.30		1.44		46.00		9.62	
		93.13	93.31	1.00	1.24	41.65	43.11	9.87	9.56
		93.50		1.27		41.68		9.18	
	III	92.50		1.23		48.79		9.81	
		92.49	92.35	1.35	1.30	44.44	45.90	9.87	9.93
		92.07		1.32		44.48		10.12	
	IV	89.35	90.60	1.21		41.32	42.33	9.58	9.25
		91.84		1.00	1.20	43.35		8.92	
				1.39					
July 20, 1972	I	97.95		1.50	1.50	49.54		9.66	
II-B-S-25		95.79	97.44+			51.22	50.42+	9.83	9.70+
	II	98.57		1.42	1.40	50.51		9.63	
				1.38					
	III			1.53	1.50				
				1.47					
	IV			1.54	1.54				
July 23, 1970	I	92.93		1.67		33.41		11.36	
III-A-S-25		93.25	93.02	1.46	1.61	44.28	39.98	11.07	11.39
		92.88		1.72		42.26		11.74	
	II	94.23		1.66		38.21		9.41	
		94.30	94.12	1.70	1.65	36.38	36.59	8.62	9.06
		93.82		1.61		35.18		9.15	
	III	93.35		1.74		40.28		10.74	
	&	93.32	93.36	1.73	1.71	41.25	39.45	10.32	10.45
	IV	93.42		1.67		36.82		10.29	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
August 5, 1970	I	93.05		1.38		55.31		10.46	
III-B-S-25#		93.16	93.08	1.48	1.41	53.51	55.12	9.76	10.10
		93.03		1.37		56.55		10.08	
	II	93.19		3.09		49.58	54.32	10.40	
		93.22	93.22	2.77	2.90	59.06		11.04	10.63
		93.23		2.83				10.44	
	III	93.84		1.41		53.36		10.62	
		93.25	93.43	1.48	1.47	53.51	53.36	10.31	10.42
		93.21		1.51		53.21		10.32	
	IV	93.50		1.53		52.09		10.50	10.48
		93.29	93.29	1.60	1.54	50.49	51.28	10.46	
		93.09		1.49		51.30			
August 21, 1970	I	95.35		1.75		57.52		11.23	11.30
III-A-S-100#		96.23	95.75	1.61	1.68	50.78	55.24	11.37	
		95.69		1.67		57.41			
	II	94.79		1.17		52.28	51.53	10.26	
		94.77	94.67	1.58	1.45	50.78		11.12	10.93
		94.46		1.60				11.40	
	III	94.56	94.86	1.71		52.09	54.34	11.20	11.12
		95.16		1.80	1.79	56.59		11.03	
				1.83					
	IV	94.29		1.63		51.68		11.25	
		94.47	94.26	1.80	1.62	53.18	50.57	12.41	11.75
		94.01		1.43		46.84		11.58	
Sept. 4, 1970	I	89.92		1.61[a]		44.40		10.28	
		88.68	89.61	1.56[a]	1.57[a]	52.54	44.01	10.18	10.41
		90.22		1.53[a]		35.10		10.78	
				1.64[b]					
				1.58[b]	1.61[b]				
				1.60[b]					

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
	II	90.04		1.53		46.05	48.22	10.61	
		89.07	89.77	1.65	1.60	50.40		10.40	10.25
		90.19		1.61				9.73	
	III	89.99		1.67	1.81			10.79	
		90.34	89.89	1.95		52.05	51.18	10.79	10.60
		89.33				59.44		10.23	
	IV	88.38		1.63		49.01		11.16	
		88.48	88.54	1.64	1.61	47.70	48.52	11.20	11.17
		88.76		1.55		48.86		11.15	
Sept. 11, 1970	I	91.79		1.44		47.44		8.78	
V-A-S-25#		91.53	92.00	1.46	1.42	51.34	46.89	10.17	9.71
		92.67		1.35		41.89		10.17	
	II	91.42		1.45		46.84		9.44	
		92.08	91.85	1.50	1.48	47.25	46.29	8.77	9.18
		92.06		1.50		44.63		9.33	
	III	92.86		1.66		47.74		9.99	
		92.50	92.79	1.66	1.63	67.88	54.00	10.25	10.17
		93.00		1.56		46.39		10.25	
	IV	92.72		1.61		41.28		11.08	
		93.26	93.01	1.40	1.54	28.80	49.46	10.39	10.69
		93.06		1.61		78.30		10.60	
Sept. 25, 1970	I	93.57		1.41		47.70		10.75	10.97
V-A-S-100#		91.27	92.17	1.36	1.39	49.39	48.42	11.18	
		91.67		1.41		48.19			
	II	94.74		1.26		45.90		9.82	
		92.74	92.90	1.29	1.25	45.26	46.20	6.40	8.54
		91.23		1.20		47.44		9.41	
	III	92.69		1.54		50.18		10.27	
		91.72	92.36	1.50	1.52	44.78	47.20	10.18	10.24
		92.66		1.52		46.69		10.18	
	IV	92.99		1.43		44.10		10.21	
		92.23	93.03	1.37	1.39	46.20		9.29	9.05
		93.87		1.38		46.73		7.64	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
October 9, 1970 V-B-S-100	I	94.74		1.41[a]					
		93.61	94.39	1.36[a]	1.38[a]				
		94.82		1.37[a]					
				1.37[b]					
				1.43[b]	1.40[b]				
				1.40[b]					
	II	93.20		1.50[a]					
		92.79	92.98	1.50[a]	1.52[a]				
		92.96		1.55[a]					
				1.51[b]					
				1.58[b]	1.54[b]				
				1.52[b]					
	III	93.82		1.66[a]					
		92.61	93.04	1.62[a]	1.63[a]				
				1.62[a]					
				1.64[b]					
				1.61[b]	1.62[b]				
				1.61[b]					
	IV	93.68		1.69[a]					
		93.63	93.82	1.49[a]	1.60[a]				
		94.15		1.61[a]					
				1.56[b]					
				1.54[b]	1.54[b]				
				1.53[b]					
October 29, 1970 VI-A-H-25#	I	87.05		2.47		43.99		8.65	
		86.89	86.68	2.44	2.42	49.12	46.25	8.01	8.34
		86.10		2.36		45.64		8.35	
	II	85.42		2.50		39.60		7.78	
		86.10	85.96	2.46	2.50	40.45	42.15	7.99	7.96
		86.37		2.54		46.39		8.10	
	III	83.33		2.94		40.19		7.72	
		83.38	83.08	3.05	2.95	37.91	41.00	7.76	7.77
		82.52		2.87		44.89		7.82	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
	IV	76.30		4.34		35.18		7.13	
		76.44	76.45	3.67	3.97	37.50	36.81	7.24	7.21
		76.62		3.89		37.76		7.26	
Nov. 13, 1970	I	88.67		1.77		44.89		8.92	
VI-B-H-25#		89.36	89.12	1.87	1.82	40.61	43.36	9.32	9 04
		89.36		1.81		44.59		8.88	
	II	87.60		2.22		42.90		9.39	
		87.93	87.62	2.04	2.12	68.96	54.16	9.13	9.39
		87.32		2.09		50.63		9.66	
	III	86.70		2.28		45.71		6.13	
		86.18	86.46	2.19	2.24	46.39	46.75	9.42	8.35
		86.50		2.26		48.15		9.50	
	IV	85.30		2.39		39.52		8.44	
		84.56	84.88	2.46	2.46	43.12	41.26	8.89	8.70
		84.79		2.53		41.14		8.78	
Nov. 25, 1970	I	89.74		2.02		52.08		9.70	
VI-A-H-100#		88.78	89.24	1.96	2.00	45.86	48.37	9.22	9.38
		89.19		2.01		47.18		9.22	
	II	87.64		2.07		47.36		8.68	
		88.18	88.04	2.02	2.12	49.91	47.57	9.02	8.92
		88.31		2.28		45.45		9.05	
	III	86.42		2.39		50.48		9.39	
		87.50	86.80	2.40	2.39	43.73	46.94	9.43	9.39
		86.48		2.37		46.61		9.36	
	IV	84.29		2.79		51.23		8.22	
		85.24	84.49	2.88	2.82	48.49	50.97	7.87	8.16
		83.93		2.80		53.18		8.40	
Dec. 9, 1970	I	87.50		1.73		42.74		9.05	
VI-B-H-100#		89.37	89.00	1.68	1.76	46.16	42.18	9.12	8.88
		90.14		1.86		37.58		8.47	
	II	88.96		2.43		43.54		8.78	
		87.66	87.47	2.37	2.35	42.00	43.86	9.14	8.79
		85.80		2.26		46.05		8.44	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus*		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
	III	86.16		2.37		34.54		9.45	
		87.78	87.05	2.35	2.29	36.94	39.05	9.29	9.38
		87.22		2.16		45.68		9.41	
	IV	84.58		2.80		46.01		9.01	
		84.97	85.03	2.81	2.82	54.49	48.17	9.33	9.57
		85.55		2.84		44.02		10.38	
Dec. 22, 1970	I	88.77		2.09		45.53		9.27	
VII-A-S-25#		89.47	89.28	1.86	1.93	47.40	47.23	8.84	8.67
		89.61		1.85		48.75		7.90	
	II	87.72		2.50		45.77		7.56	
		87.89	87.83	2.35	2.39	46.88	45.88	7.78	7.60
		87.89		2.32		45.00		7.46	
	III	87.96		2.20		44.66		7.73	
		88.86	88.23	2.14	2.21	44.85	44.81	7.93	7.44
		87.87		2.29		44.92		6.67	
	IV	87.31		2.11		44.93		7.82	7.53
		86.97	87.23	2.10	2.09	45.69	45.95	7.56	
		87.42		2.06		47.32		7.22	
Jan. 11, 1971	I	86.92		2.01		48.41		8.99	
VII-B-S-25#		87.88	87.45	1.98	2.01	49.05	48.20	8.27	8.62
		87.56		2.05		47.14		8.61	
	II	90.88		1.58		47.10		8.10	
		90.63	90.72	1.61	1.61	46.58	47.04	7.94	8.04
		90.64		1.65		47.44		8.09	
	III	92.23		1.57		47.25		8.42	8.23
		92.48	92.29	1.65	1.61	48.08	48.73	8.03	
		92.15		1.61		50.85		6.83[c]	
	IV	89.96		2.09		45.83		8.95	
		89.92	89.60	2.11	2.13	47.96	47.55	8.87	8.97
		89.02		2.20		48.82		9.09	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Phosphorus* Each Sample	% Phosphorus* Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
Jan. 29, 1971 VII-A-S-100#	I	85.20	85.20	1.81	1.81	47.74	47.74	9.30	9.30
				1.81					
	II	85.91	85.91	1.73	1.73	48.30	48.30	9.31	9.31
				1.73					
	III	88.77	88.77	1.67	1.66	47.89	47.29	9.35	9.35
				1.64		46.69			
	IV	86.05	86.05	1.84	1.90	48.41	48.41	9.39	9.39
				1.96					
Feb. 12, 1971 VII-A-S-10#	I	87.78		1.87		49.97		9.37	
		87.23	88.16	2.15	2.07	49.56	49.59	9.52	9.46
		89.49		2.18		49.24		9.48	
	II	89.47		1.67		48.41		8.89	
		88.65	88.73	1.73	1.82	48.82	48.41	9.26	9.24
		88.08		2.06		47.99		9.57	
	III	86.34		1.96		50.86		9.41	
		87.39	86.82	1.90	1.92	47.06	49.52	9.39	9.45
		86.75		1.89		50.64		9.56	
	IV	89.22		1.63		49.92		9.46	9.70
		89.67	89.66	1.91	1.80	47.89	49.60	9.94	
		90.09		1.87		51.00			
Feb. 24, 1971 VIII-A-H-10#	I	88.87		1.67		49.81		6.86	
		90.02	89.45	1.68	1.72	50.59	49.65	8.67	7.81
		89.46		1.81		48.54		7.91	
	II	89.31		1.84		50.40		9.04	
		88.17	89.03	1.87	1.85	48.79	49.49	9.85	9.74
		89.60		1.85		49.28		10.34	
	III	88.39		2.16		45.71		8.50	9.62
		86.94	87.70	2.24	2.16	49.48	46.86	10.74	
		87.76		2.09		45.38			
	IV	87.54		2.16	2.16	44.31		10.00	9.54
		87.88	87.24	2.16		53.96	49.93	9.09	
		86.31				46.41			
						55.05			

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
March 10, 1971	I	87.69		1.43		43.73		8.63	
VIII-B-H-10#		87.78	87.81	1.44	1.42	45.08	44.44	8.80	8.60
		87.95		1.39		44.51		8.36	
	II	85.67		2.08		44.68		8.65	
		85.66	85.55	2.45	2.22	46.89	45.69	8.82	8.79
		85.31		2.14		45.49		8.91	
	III	85.65		2.13		45.28	45.70	8.42	
		85.15	85.05	1.82	2.03	46.11		8.56	8.38
		84.36		2.14				8.17	
	IV	88.28		1.90		48.19		8.47	
		87.98	87.83	2.01	1.97	47.63	47.34	8.38	8.32
		87.22		1.99		46.19		8.10	
March 26, 1971	I	89.68		1.24		52.03		10.17	
IX_L-A-H-10#		92.02	91.19	1.48	1.50	49.93	51.08	9.82	10.00
		91.88		1.78		51.28		10.01	
	II	89.82		1.49		46.52		10.25	
		91.43	90.83	1.63	1.52	50.96	48.39	9.98	10.00
		91.24		1.45		47.70		9.78	
	III	88.27		1.80		44.21		9.10	
		89.60	89.24	1.74	1.79	46.28	46.30	10.40	9.66
		89.84		1.84		48.41		9.48	
	IV	90.17		1.84		47.44		8.06	
		88.93	89.71	1.65	1.84	46.98	47.06	9.95	9.21
		90.03		2.04		46.76		9.63	
April 14, 1971	I	89.64		1.22	1.245	46.18	46.18	10.16	
IX_L-B-H-10#		90.05	89.91	1.27				10.28	10.19
		90.04						10.13	
	II	89.80		1.23	1.245	45.67	45.67	9.93	
		89.78	89.95	1.26				9.24	9.88
		90.27						9.87	
	III	90.14		1.38	1.415	45.52	45.52	9.53	
		90.73	90.51	1.45				9.79	9.68
		90.65						9.71	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids Each Sample	% Volatile Solids Avg.	% Phosphorus Each Sample	% Phosphorus Avg.	% Carbon Each Sample	% Carbon Avg.	% Nitrogen Each Sample	% Nitrogen Avg.
	IV	88.07		1.33	1.365	46.42	46.42	9.92	
		88.63	88.54	1.40				9.78	9.88
		88.93						9.93	
April 30, 1971	I	90.88		1.17		51.23		10.21	
IX_L-A-H-50#		90.60	90.34	1.16	1.16	51.38	51.62	9.99	10.10
		89.55		1.15		52.24		10.11	
	II	89.25		1.40		56.04		9.83	
		88.34	88.63	1.18	1.28	52.39	53.70	9.70	9.95
		88.29		1.25		52.66		10.32	
	III	88.44		1.37		48.94	49.93	9.54	9.54
		88.15	88.05	1.46	1.39	50.92		9.53	
		87.56		1.35					
	IV	89.71		1.55	1.52	52.05		9.04	
		88.39	88.92	1.49		50.83	51.21	8.83	9.03
		88.67				50.74		9.21	
May 19, 1971	I	92.30		1.07		49.43		9.03	
IX_L-A-H-100#		92.11	92.05	1.00	1.06	52.65	51.34	9.36	9.13
		91.74		1.12		51.94		9.01	
	II	91.75		1.35		49.60		9.60	
		91.21	91.34	1.32	1.32	47.93	49.36	9.70	9.57
		91.05		1.28		50.55		9.40	
	III	90.31		1.50		51.38		9.06	
		90.03	90.22	1.52	1.36	50.95	51.51	10.35	9.71
		89.43		1.06		52.20		9.71	
	IV	91.20		1.62		46.87		9.60	
		89.87	90.58	1.56	1.59	45.68	47.68	9.40	9.48
		90.66		1.58		50.48		9.43	
June 4, 1971	I	90.73		1.57		46.01		9.51	
X_L-A-H-10#		90.20	90.59	1.51	1.58	44.98	45.28	9.28	9.34
		90.83		1.65		44.86		9.32	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
	II	89.78		1.73		44.89		9.96	
		89.41	89.57	1.86	1.78	44.85	44.86	9.52	9.72
		89.52		1.74		43.84		9.67	
	III	88.61		2.19		44.93		10.05	
		88.51	88.55	2.06	2.18	45.94	44.06	9.95	9.95
		88.52		2.28		41.32		9.84	
	IV	85.76		2.72		41.98		9.23	
		85.92	95.69	2.60	2.71	46.65	44.10	9.25	9.32
		85.38		2.81		43.67		9.47	
June 23, 1971	I	89.99		1.35		45.00		8.31	
X_L-A-H-100#		90.08	90.05	1.56	1.40	47.32	46.86	8.37	8.55
		90.08		1.30		48.27		8.98	
	II	89.74		1.53		45.26		8.41	8.39
		90.28	89.89	1.64	1.59	45.00	45.26	8.37	
		89.64		1.61		45.52			
	III	87.42		2.45		43.88		8.67	
		86.05	86.54	2.39	2.44	45.04	44.20	8.53	8.38
		86.16		2.48		43.69		7.95	
	IV	83.87		2.94		43.35		8.58	
		83.57	83.83	2.91	3.00	43.88	43.45	8.62	8.48
		84.04		3.15		43.13		8.24	
July 2, 1971	I	83.45		1.52		43.99		10.89	
VIII$_L$-A-H-10#		89.96	87.94	1.55	1.52	47.40	48.26	10.42	10.61
		90.41		1.48		53.40		10.52	
	II	88.66		1.59		45.00		9.91	
		88.56	88.44	1.72	1.69	47.14	45.76	10.53	10.02
		88.25		1.75		45.15		9.62	
	III	95.74		1.77	1.79	43.65		10.02	
		89.05	91.10	1.80		43.61	44.24	11.48	10.53
		88.52				45.45		10.10	
	IV	88.28		1.95		44.85		9.68	
		88.10	88.17	1.90	1.94	41.81	43.62	9.72	9.60
		88.12		1.98		44.21		9.41	

TABLE 13 (continued)

Date and Identification	Disc	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
July 19, 1971	I	87.24		1.73		44.96		8.99	8.51
$VIII_L$-A-H-100#		87.13	87.21	1.66	1.63	44.18	44.64	8.03	
		87.27		1.51		44.78			
	II	82.37		2.00		42.49		8.55	8.46
		82.92	82.80	2.17	2.15	43.94	43.26	8.37	
		83.12		2.28		43.35			
	III	81.06		2.67		45.94		7.66	
		80.82	80.86	2.81	2.72	40.99	43.66	8.15	7.93
		80.71		2.69		44.04		7.99	
	IV	80.52		2.91	2.56	39.68		7.73	
		80.00	80.11	2.21		41.55	40.74	7.36	7.49
		79.82				40.99		7.39	

* On dry weight basis
\+ Composite from four discs
** All these slime samples were taken from the settling cones
\# Test runs included in statistical analysis
[a] After washing with deionized water
[b] Before washing with deionized water
[c] Problem with laboratory analysis

TABLE 14
PERCENT CALCIUM AND MAGNESIUM
IN DISC SLIMES

Date and Identification	Disc	Percent on Dry Weight Basis Ca Each Sample	Ca Ave.	Mg Each Sample	Mg Ave.
October 9, 1970 V-B-S-100	I	0.51			
		0.50	0.48		
		0.42			
	II	0.48			
		0.50	0.47		
		0.42			
	III	0.53			
		0.49	0.53		
		0.58			
	IV	0.39			
		0.46	0.41		
		0.37			
November 13, 1970 VI-B-H-25	I	2.18	1.88		
		1.58			
	II	1.86			
		1.76	1.81		
		1.82			
	III	2.17			
		2.33	2.23		
		2.20			
	IV	3.13			
		2.71	2.89		
		2.83			
November 25, 1970 VI-A-H-100	I	2.12	2.18	.21	.215
		2.24		.22	
	II	2.84		.25	
		2.61	2.63	.21	.22
		2.44		.20	
	III	3.55		.23	
		3.46	2.98	.26	.25
		1.92		.26	
	IV	4.14		.26	
		3.67	4.01	.23	.25
		4.22		.26	
December 9, 1970 VI-B-H-100	I	1.49			
		1.42	1.46		
		1.48			
	II	3.25			
		3.07	2.98		
		2.61			

TABLE 14 (continued)

Date and Identification	Disc	Percent on Dry Weight Basis			
		Ca		Mg	
		Each Sample	Ave.	Each Sample	Ave.
	III	3.73			
		3.39	3.47		
		3.30			
	IV	4.39			
		4.27	4.45		
		4.70			
December 22, 1970	I	.71		.23	
VII-A-S-25		.66	.69	.20	.21
		.69		.19	
	II	1.97	1.88	.22	.22
		1.79		.22	
	III	1.71	1.58	.19	.18
		1.44		.17	
	IV	1.92	1.88	.15	.17
		1.83		.19	
January 11, 1971	I	.71		.17	
VII-B-S-25		.75	.72	.18	.173
		.70		.17	
	II	1.29		.13	
		1.12	1.22	.13	.13
		1.24		.13	
	III	1.99		.12	
		2.00	2.04	.11	.13
		2.15		.15	
	IV	2.89		.12	
		2.88	2.87	.14	.13
		2.83		.13	
January 29, 1971	I	.40	.41	.105	.106
VII-A-S-100		.41		.106	
	II	.81	.82	.08	.09
		.83		.09	
	III	1.04	1.04	.08	.08
	IV	1.66	1.60	.08	.08
		1.53		.08	
February 12, 1971	I	.36		.11	
VII-A-S-10		.48	.41	.13	.12
		.38		.12	
	II	.80		.09	
		.84	.81	.10	.10
		.79		.10	

TABLE 14 (continued)

Date and Identification	Disc	Percent on Dry Weight Basis			
		Ca		Mg	
		Each Sample	Ave.	Each Sample	Ave.
	III	.60		.06	
		1.12	1.11	.10	
		1.10		.10	
	IV	1.15		.086	
		1.78	1.45	.108	.094
		1.41		.087	
February 24, 1971 VIII-A-H-10	I	1.79		.41	.40
		1.90	1.82	.39	
		1.76			
	II	1.74		.33	.33
		1.82	1.78		
		1.78			
	III	2.17		.24	
		2.25	2.18	.24	.243
		2.12		.25	
	IV	1.90		.26	
		1.99	2.04	.26	.27
		2.24		.28	
March 10, 1971 VIII-B-H-10	I	3.50		.31	
		3.99	3.73	.32	.31
		3.71		.30	
	II	3.03		.40	.39
		2.95	2.98	.38	
		2.95			
	III	4.28		.42	
		3.94	4.02	.36	.39
		3.85		.38	
	IV	2.46		.34	
		2.54	2.77	.36	.35
		3.30			
March 26, 1971 IX_L-A-H-10	I	.57	.57	.01	.01
	II	.70			
		.69	.70		
		.71			
	III	.64			
		.70	.70		
		.75			
	IV	1.15		.35	
		1.37	1.36	.35	.34
		1.56		.31	

TABLE 14 (continued)

Date and Identification	Disc	Percent on Dry Weight Basis			
		Ca		Mg	
		Each Sample	Ave.	Each Sample	Ave.
April 14, 1971	I	.75			
IX_L-B-H-10		.82	.82		
		.89			
	II	.84			
		.89	.88		
		.91			
	III	1.19			
		1.17	1.16		
		1.11			
	IV	1.19			
		1.06	1.14		
		1.17			
April 30, 1971	I	.79			
IX_L-A-H-50		.82	.82		
		.85			
	II	1.02	.94		
		.86			
	III	1.11			
		1.06	1.08		
		1.06			
	IV	1.36			
		1.37	1.39		
		1.43			
May 19, 1971	I	.84		.30	.29
IX_L-A-H-100		.82	.82	.27	
		.80			
	II	1.04		.37	
		1.07	1.06	.30	.33
		1.07		.32	
	III	1.17	1.18	.34	.34
		1.20			
	IV	1.47		.31	.32
		1.50	1.47	.32	
		1.44			
June 4, 1971	I	1.59		.23	
X_L-A-H-10		2.17	2.13	.22	.22
		2.09		.21	
	II	1.58	1.64	.23	.23
		1.70		.23	
	III	1.65		.25	.24
		1.97	1.86	.24	
		1.95			

TABLE 14 (continued)

Date and Identification	Disc	Percent on Dry Weight Basis Ca Each Sample	Ca Ave.	Mg Each Sample	Mg Ave.
	IV	2.78		.25	.27
		2.86	2.86	.28	
		2.93			
June 23, 1971 X_L-A-H-100	I	1.75		.24	
		1.59	1.64	.20	.23
		1.57		.24	
	II	2.30		.23	
		2.46	2.34	.19	.21
		2.26		.22	
	III	2.84		.26	
		3.48	3.21	.26	.26
		3.31		.27	
	IV	4.05		.26	
		4.00	4.06	.31	.29
		4.14		.30	
July 2, 1971 $VIII_L$-A-H-10	I	1.46		.24	
		1.26	1.36	.25	.24
		1.37		.24	
	II	2.12		.30	
		1.96	2.03	.34	.31
		2.00		.30	
	III	1.89		.29	
		2.02	1.94	.30	.29
		1.92		.28	
	IV	2.94	2.88	.29	.29
		2.71		.29	
July 19, 1971 $VIII_L$-A-H-100	I	3.12	3.06	.29	.30
		3.00		.31	
	II	4.04		.37	
		4.37	4.22	.39	.36
		4.26		.31	
	III	4.50		37	
		4.77	4.60	.47	.41
		4.54		.38	
	IV	6.51		.46	
		5.36	5.20	.39	.40
		5.04		.34	

TABLE 15
ANALYSIS OF CHANNEL SLIMES
PRELIMINARY RUNS

Date and Identification	Channel	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
		Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
March 26, 1971	Comp.*	91.4		1.24		49.50		10.48	
Milk(24 g./80L)		91.2	91.3	1.25	1.30	49.44	49.53	9.90	10.21
only feed		91.3		1.40		49.66		10.26	
April 16, 1971	I			1.21	1.175				
Milk only,				1.14					
4.0 ml/min.	II			1.20	1.17				
Mid-slope				1.14					
	III			1.22					
				1.20	1.16				
				1.09					
	IV			1.17				10.73	10.74
				1.19	1.18			10.74	
				1.19					
June 1, 1971	I			2.15	2.02				
Milk(36g/80L),				1.89					
80ml N.B. sol'n	II			2.00				8.65	8.65
(450mg/ml), 20ml				2.02	1.99				
Na_2HPO_4(20mgP/ml)				1.96					
	III	88.6	88.6	1.97				8.94	8.99
				2.10	2.04			9.02	
				2.04					
	IV	87.8	87.3	2.21				8.07	8.13
		86.8		2.09	2.19			8.18	
				2.26					

* Average percent of calcium in slime = 0.62%.

TABLE 16
FEED AND EFFLUENT ANALYSES
REMOVAL-STORAGE COMPARISON RUNS ON CHANNEL APPARATUS

Run	Comments	Date	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
I	Low slope. 4 ml/min. 24 mg milk solids/80L. 50 ml stock P sol'n. (12 mg P/ml=7.5 mg P/L + milk)	4-19-71	9.05	318	15.2	I	9.71	343	22.3
						II	9.85	326	21.9
						III	8.98	289	19.3
						IV	9.46	275	20.3
		4-20-71	8.95	265	15.7	I	9.44	219	16.1
						II	9.44	199	13.9
						III	8.83	170	12.1
						IV	9.63	141	11.9
		4-22-71	8.49	314	15.4	I	8.49	285	17.4
						II	8.58	281	17.7
						III	14.10	273	19.0
						IV	8.38	240	17.9
II	Mid slope. Same feed as I. Same rate as I.	4-27-71	8.64	301	16.1	I	8.56	255	14.5
						II	9.05	238	14.7
						III	7.72	188	11.7
						IV	8.47	265	11.4
		4-28-71	8.40	339	16.4	I	8.38	291	14.7
						II	8.59	283	13.8
						III	8.09	266	14.2
						IV	7.96	261	13.7
		4-29-71	8.17	313	13.8	I	8.13	230	10.0
						II	8.15	224	9.2
						III*	7.89	178	9.8
						IV*	7.80	167	8.9
		5-4-71	7.41	331	14.5	I	8.80	254	14.1
						II	8.36	239	13.3
						III	8.31	181	11.9
						IV	9.08	164	11.3

TABLE 16 (continued)

Run	Comments	Date	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
		5-5-71	8.83	365	15.4	I	9.05	298	15.9
						II	8.85	279	15.5
						III	8.95	270	15.7
						IV	8.93	262	16.3
		5-6-71	8.83	3[illegible]6	14.7	I	8.45	249	10.4
						II	8.38	227	10.2
						III	8.59	193	11.1
						IV	9.10	187	11.4
III	Mid slope. 4 ml/min. 36 g glucose, 80 ml Nutrient broth sol'n. (450 mg/ml), 20 ml Na_2HPO_4 (20mgP/ml).	6-8-71	10.03	780	55.0	I	9.07	804	55.7
						II	9.07	780	60.7
						III	8.78	760	56.0
						IV	9.94	812	58.5
		6-9-71	10.00	932	59.5	I	7.94	772	54.0
						II	9.13	772	55.5
						III	8.43	788	53.9
						IV	8.58	796	56.7
		6-11-71	9.38	924	61.8	I	9.05	824	57.8
						II	9.41	768	59.3
						III	8.31	820	55.7
						IV	10.03	779	56.7
IV	Low slope. Same feed and rate as III.	6-14-71	7.20	959	60.2	I	9.78	734	52.3
						II	6.07	827	60.4
						III	8.72	850	59.3
						IV	6.53	858	52.3
		6-15-71	10.19	928	64.4	I	11.30	928	64.6
						II	9.07	802	57.2
						III	10.25	858	56.5
						IV	10.06	771	56.2
		6-18-71	10.91	935	63.4	I	26.08	862	59.9
						II	10.14	838	56.9
						III	9.32	834	55.7
						IV	10.06	798	52.0

TABLE 16 (continued)

Run	Comments	Date	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
V	High slope. Same feed and rate as III.	6-21-71	9.94	942	60.7	I	8.34	770	50.4
						II	10.58	742	55.4
						III	10.38	774	56.5
						IV	9.35	770	57.4
		6-22-71	10.38	880	60.2	I	10.68	701	46.3
						II	9.63	748	52.3
						III	10.03	788	56.0
						IV	8.52	741	53.7
		6-23-71	13.54	935		I	8.52	719	*
						II	9.69	781	*
						III	13.13	765	*
						IV	9.08	715	*
VI	Mid slope. 75g glucose, 25 g milk, 15 ml Na_2HPO_4 (20mgP/ml), 80ml NH_4Cl (48mgN/ml)/80L. 5.4 ml/min. Separate tubing for collection.	7-6-71	6.98	1356	70.9	I	5.76	1290	59.3
						II	6.29	1310	66.6
						III	5.94	1325	63.7
						IV	5.32	1193	63.5
		7-7-71	7.85	1341	65.6	I	6.43	1255	61.0
						II	5.28	1189	57.9
						III	5.79	1015	46.7
						IV	5.22	1255	44.9
		7-8-71	5.42	1342	70.0	I	5.30	1272	66.9
						II	5.00	1280	57.8
						III	3.62	1117	54.8
						IV	3.02	974	45.9
VII	High slope. Same feed and rate as VI.	7-14-71	5.62	1324	62.7	I	5.10	1284	65.5
						II	4.30	1260	62.7
						III	4.46	1244	61.04
						IV	4.06	1208	64.6
		7-15-71	5.46	1336	58.8	I	5.31	1304	64.1
						II	4.50	1280	56.8
						III	4.75	1216	56.5
						IV	3.44	1128	50.4

TABLE 16 (continued)

Run	Comments	Date	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
		7-16-71	5.73	1383	57.4	I	5.03	1312	65.5
						II	4.58	1288	62.4
						III	4.21	1272	59.3
						IV	3.98	1161	58.8
VIII	Low slope. Same feed and rate as VI.	7-20-71	5.47	1298	63.2	I	5.30	1275	56.5
						II	5.01	1294	59.9
						III	4.79	1279	56.5
						IV	4.53	1228	61.0
		7-21-71	5.73	1317	66.3	I	4.51	1262	59.9
						II	4.51	1215	59.3
						III	4.15	1219	57.6
						IV	4.06	1183	62.1
		7-22-71	5.94	1309	70.0	I	4.51	1238	68.6
						II	4.41	1183	60.2
						III	4.14	1159	59.9
						IV	3.61	1088	48.7

*Analysis problem

TABLE 17
ANALYSIS OF CHANNEL SLIMES
REMOVAL-STORAGE COMPARISON RUNS

Run	Date	Channel	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
			Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
I	4-23-71	I			1.35	1.34				
					1.34					
		II			1.39	1.39				
		III			1.47	1.50				
					1.54					
		IV			1.43	1.43				
II	5-20-71	I			1.25	1.23				
					1.21					
		II			1.24				11.21	11.21
					1.13	1.20				
					1.22					
		III	87.0	87.0	1.16				10.36	
					1.23	1.22			10.51	10.58
					1.27				10.88	
		IV	85.4	85.4	1.14				10.40	
					1.25	1.14			10.58	10.40
					1.02				10.20	
III	6-11-71	I			1.72					
					1.53	1.62				
		II	93.1	93.1	1.51				8.97	9.28
					1.57	1.53			9.58	
					1.52					
		III			1.55				10.06	9.90
					1.59	1.58			9.74	
					1.61					
		IV			1.50					
					1.56	1.61				
					1.77					

TABLE 17 (continued)

Run	Date	Channel	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
			Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
IV	6-18-71	I			1.32	1.47				
					1.62					
		II			1.77				9.77	9.77
					1.60	1.70				
					1.74					
		III			1.88				8.80	9.90
					1.63	1.69				
					1.57					
		IV			1.62				9.71	9.85
					1.76	1.74			9.99	
					1.85					
V	6-25-71	I			1.58				9.63	9.63
					1.81	1.74				
					1.83					
		II	88.72	88.57	2.20				10.04	
			88.41		1.86	2.09			10.01	9.90
					2.20				9.64	
		III	91.65		1.68				10.34	
			88.92	89.73	1.63	1.73			10.40	10.35
			88.64		1.85				10.30	
		IV	90.00		1.68				11.53	11.46
			91.56	90.61	1.85	1.69			11.38	
			90.26		1.53					
VI	7-9-71	I			1.97					
					1.98	1.92				
					1.82					
		II	86.13	86.13	2.57				9.36	
					2.27	2.23			8.26	8.59
					1.85				8.14	
		III	88.47	88.47	1.76				10.39	10.30
					1.72	1.73			10.22	
					1.71					

TABLE 17 (continued)

Run	Date	Channel	% Volatile Solids		% Phosphorus		% Carbon		% Nitrogen	
			Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.	Each Sample	Avg.
		IV	84.66	84.66	1.69				10.62	11.04
					1.81	1.71			11.46	
					1.62					
VII	7-16-71	I			*					
		II			2.30	2.11				
					1.92					
		III			1.82					
					2.27	2.11				
					2.23					
		IV	89.18		2.04				9.90	
			90.77	89.98	2.25	2.10			9.60	9.76
					2.02				9.78	
VIII	7-23-71	I			1.66				11.12	11.12
					1.98	1.90				
					2.05					
		II			1.95				9.28	9.28
					2.01	1.99				
					2.00					
		III	88.35	88.80	1.79				9.79	
			89.24		1.71	1.74			9.13	9.72
					1.71				10.25	
		IV	87.13		2.01				9.93	
			84.51	85.84	2.01	2.05			9.39	9.70
			85.89		2.13				9.78	

*Analysis problem.

TABLE 18
FEED AND EFFLUENT ANALYSES
ULTRAVIOLET STUDIES ON CHANNEL APPARATUS

Run	Date	Slope	Comments	Time	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
I	8-11-71	Mid	Milk, Glucose, Na_2HPO_4 Cl for feed as last study (removal-storage comp.)	Initial	5.61	1215	60.7	I	3.22	897	*
								II	2.74	782	40.8
								III	2.18	741	39.4
								IV	1.46	602	*
				UV-1	5.61	1214	58.5	I	5.28	1072	50.6
								II	6.12	1052	52.6
								III	6.43	1092	53.2
								IV	6.76	1028	59.0
				UV-2	5.44	1206	59.0	I	5.32	1133	58.2
								II	5.44	1060	52.0
								III	5.68	1084	51.8
								IV	5.18	1028	55.7
	8-12-71			UV-19 1/2	5.46	1198	52.9	I	5.31	1194	59.6
								II	5.17	1133	56.8
								III	5.30	1190	61.3
								IV	5.10	1092	55.1
				UV-26	5.44	1182	64.4	I	4.99	1161	56.5
								II	4.72	1121	53.7
								III	5.44	1186	58.8
								IV	4.51	1145	53.7
II	8-16-71	Mid	Same feed as I.	Initial	5.61	1135	77.5	I	3.61	1131	54.6
								II	1.63	1015	53.7
								III	0.96	840	44.2
								IV	1.26	832	42.0
				UV-1	5.24	1215	57.6	I	6.00	1235	78.9
								II	6.79	1219	66.0
								III	7.33	117i	64.4
								IV	7.91	1199	71.4

TABLE 18 (continued)

Run	Date	Slope	Comments	Time	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
	8-17-71			UV-19	4.20	1183	46.4	I	4.27	996	46.4
								II	4.17	999	48.7
								III	3.76	980	47.3
								IV	3.62	972	49.5
				UV-24	5.44	1201	56.0	I	5.44	1217	60.4
								II	5.26	1185	58.2
								III	4.94	1161	59.9
								IV	4.94	1161	56.8
	8-18-71			UV-48	5.04	1203	63.2	I	5.31	1170	54.3
								II	5.18	1170	57.1
								III	4.99	1154	54.3
								IV	5.13	1150	57.6
	8-19-71			UV-72	5.15	1262	55.4	I	5.65	1254	63.2
								II	6.25	1258	62.1
								III	5.94	1258	67.1
								IV	6.02	1254	68.3

*Analysis Problem

TABLE 19
FEED AND EFFLUENT ANALYSES
STARVE-KILL STUDY ON CHANNEL APPARATUS

Run	Date	Slope	Comments	Time	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
I	8-23-71	Mid	Same feed as Ultraviolet study. Same rate as ultraviolet study	Initial	2.0	1331	68.0	I	0.374	1173	62.4
								II	0.289	1022	52.3
								III	-----	812	46.4
								IV	-----	761	47.0
	8-24-71		24 hrs. with H_2O feed		5.61	1296	*	I	4.51	1158	57.6
								II	4.87	923	49.5
								III	2.95	796	42.0
								IV	2.56	642	45.3
	8-25-71		24 hrs. with H_2O feed. Put on UV light, still with H_2O feed.	UV-2	5.42	1318	61.0	I	6.05	1207	58.2
								II	6.52	1065	56.2
								III	7.07	961	54.0
								IV	7.32	823	53.7
II	8-30-71	Mid	Same feed and rate.	Initial	5.61	1303	59.3	I	4.39	1136	55.7
								II	3.68	996	54.0
								III	3.10	784	45.9
								IV	2.41	791	48.7
	8-31-71		24 hrs. with H_2O feed.		5.22	1128	53.7	I	3.52	902	45.6
								II	3.39	793	41.7
								III	2.23	524	34.1
								IV	1.93	470	32.4
	9-1-71		24 hrs. with H_2O feed. Put on UV light, still with H_2O feed.	UV-2	5.61	1259	59.3	I	6.39	1148	57.4
								II	7.30	1086	56.8
								III	7.82	954	56.0
								IV	8.78	926	57.6
III	9-8-71	Mid	Same feed and rate	Initial	5.31	1325	61.0	I	3.71	1180	57.6
								II	2.33	1060	51.5
								III	0.91	935	42.2
								IV	0.30	799	46.4

TABLE 19 (continued)

Run	Date	Slope	Comments	Time	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
	9-9-71		24 hrs. with H_2O feed.		5.56	1298	60.7	I	4.82	1120	54.3
								II	4.29	991	49.8
								III	3.36	887	44.2
								IV	2.38	741	45.0
	9-10-71		24 hrs. with H_2O feed. Put on UV light, still with H_2O feed.	UV-2	5.76	1282	59.9	I	5.31	1236	53.7
								II	5.78	1083	52.8
								III	6.22	1007	53.4
								IV	6.10	892	47.6
	9-11-71		24 hrs. with H_2O feed and UV light.	UV-24	5.46	1252	57.1	I	5.08	1154	54.3
								II	5.17	1101	50.4
								III	5.14	1078	48.7
								IV	4.74	961	44.8
IV	9-14-71	Low	Same feed and rate.	Initial	1.95	1290	67.7	I	-----	1237	64.4
								II	-----	1146	62.4
								III	-----	950	57.4
								IV	-----	754	51.5
	9-15-71		24 hrs. with H_2O feed.		5.62	1255	60.7	I	3.59	955	47.3
								II	2.60	849	39.2
								III	1.75	699	32.7
								IV	-----	481	27.4
	9-16-71		24 hrs. with H_2O feed. Put on UV light, still with H_2O feed.	UV-2	5.73	1288	60.2	I	4.62	1190	56.2
								II	3.84	1167	54.3
								III	3.34	1088	55.1
								IV	3.81	888	61.6
	9-17-71		24 hrs. with H_2O feed and UV light.	UV-24	5.74	1283	60.4	I	6.07	1283	58.8
								II	4.62	1237	53.7
								III	4.88	1153	54.3
								IV	4.62	1163	50.6

TABLE 19 (continued)

Run	Date	Slope	Comments	Time	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
V	9-20-71	Low	Same feed and rate.	Initial	5.61	1243	62.4	I	3.94	1218	58.2
								II	3.48	1297	59.0
								III	3.87	1148	60.2
								IV	3.61	1115	61.3
	9-21-71		24 hrs. with H_2O feed.		5.33	1279	59.6	I	5.28	1177	56.2
								II	4.77	1076	*
								III	4.37	983	49.8
								IV	3.27	902	45.3
	9-22-71		24 hrs. with H_2O feed. Put on Light with H_2O feed.	UV-2	4.01	1303	55.4	I	1.26	1233	52.0
								II	1.22	1210	50.4
								III	1.10	1171	53.7
								IV	1.07	1108	50.9
	9-23-71		24 hrs. with H_2O feed and UV light.	UV-24	5.24	1303	58.2	I	4.33	1260	54.8
								II	3.36	1214	53.7
								III	3.62	1187	53.2
								IV	2.74	1148	51.5
VI	9-27-71	High	Same feed and rate.	Initial	5.25	1277	59.3	I	4.51	1227	57.6
								II	4.33	1219	56.0
								III	3.82	1127	54.6
								IV	3.08	1103	56.5
	9-28-71		24 hrs. with H_2O feed.		5.43	1293	59.3	I	4.50	1159	55.4
								II	4.47	1125	52.6
								III	3.81	1016	49.8
								IV	3.50	945	47.0
	9-29-71		24 hrs. with H_2O feed. Then put on UV light with H_2O feed.	UV-2	5.13	1238	48.1	I	4.98	1163	53.7
								II	4.95	1146	55.1
								III	5.61	1138	56.8
								IV	5.59	1171	57.1
	9-30-71		24 hrs. with H_2O feed and UV light.	UV-24	5.31	1255	58.8	I	4.29	1179	53.7
								II	4.09	1179	53.7
								III	5.90	1330	60.4
								IV	3.71	1217	54.8

TABLE 19 (continued)

Run	Date	Slope	Comments	Time	Feed (mg/l) Phosphorus	COD	Nitrogen	Channel	Effluent (mg/l) Phosphorus	COD	Nitrogen
VII	10-4-71	High	Same feed and rate.	Initial	6.78	1285	59.3	I	5.15	1165	56.2
								II	5.18	1140	53.2
								III	3.58	1012	50.6
								IV	3.49	942	47.0
	10-5-71		24 hrs. with H_2O feed.		5.46	1248	59.9	I	4.09	1060	52.3
								II	3.50	971	41.4
								III	3.15	838	45.3
								IV	2.03	475	39.7
	10-6-71		24 hrs. with H_2O feed. Put on UV light, with H_2O feed still on.	UV-2	5.58	1292	60.2	I	5.74	1180	55.7
								II	5.94	1164	57.1
								III	5.70	1101	55.4
								IV	6.64	1093	57.6
	10-7-71		24 hrs. with H_2O feed and UV light.	UV-24	5.61	1276	61.0	I	4.96	1184	54.3
								II	4.96	1168	52.0
								III	4.69	1105	52.0
								IV	4.79	1041	52.0

*Analysis problem.

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